

# Observational Signatures of Magnetic Reconnection in the Extended Corona

SabriNA SAverage,

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Royal Observatory  
of Belgium



*..... and First Results from the Hi-C II Sounding Rocket*

Amy Winebarger, Ken Kobayashi, Laurel Rachmeler

# Supra-Arcade Downflows (SADs) Observations



Sadpoles, not tadpoles

Fig 1

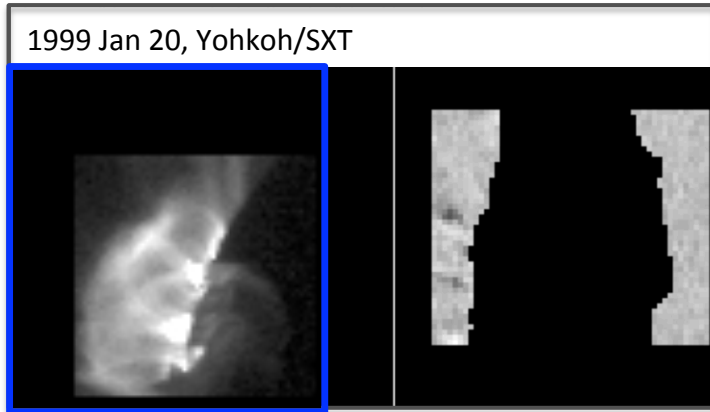


Fig 2

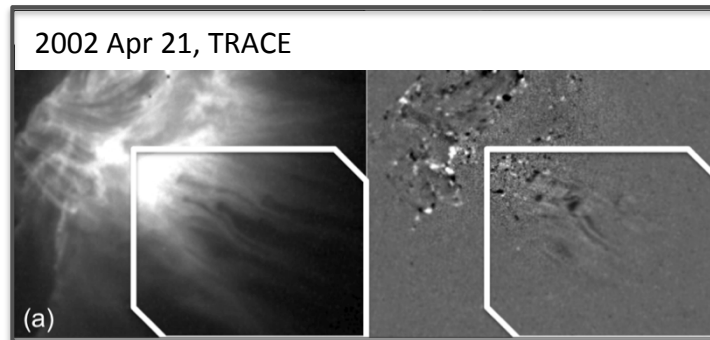


Fig 3

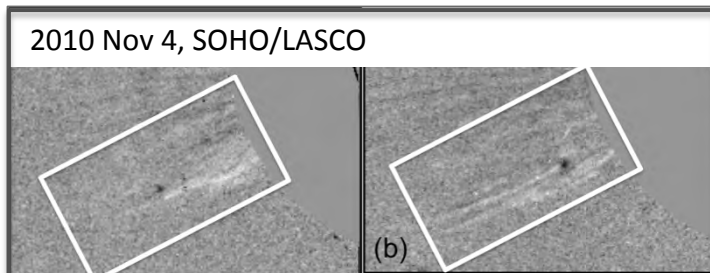
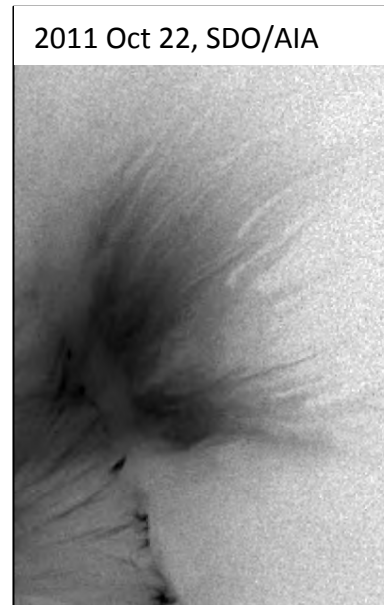
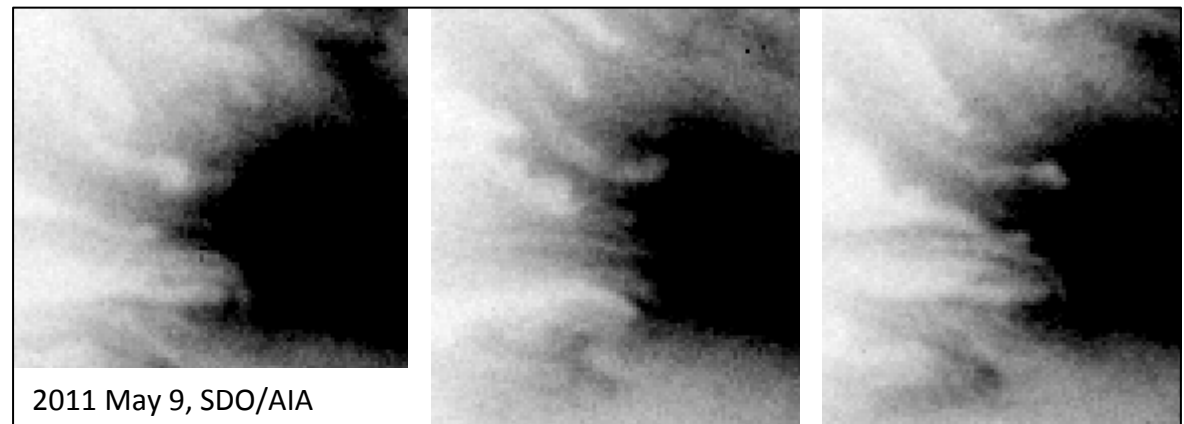


Fig 4



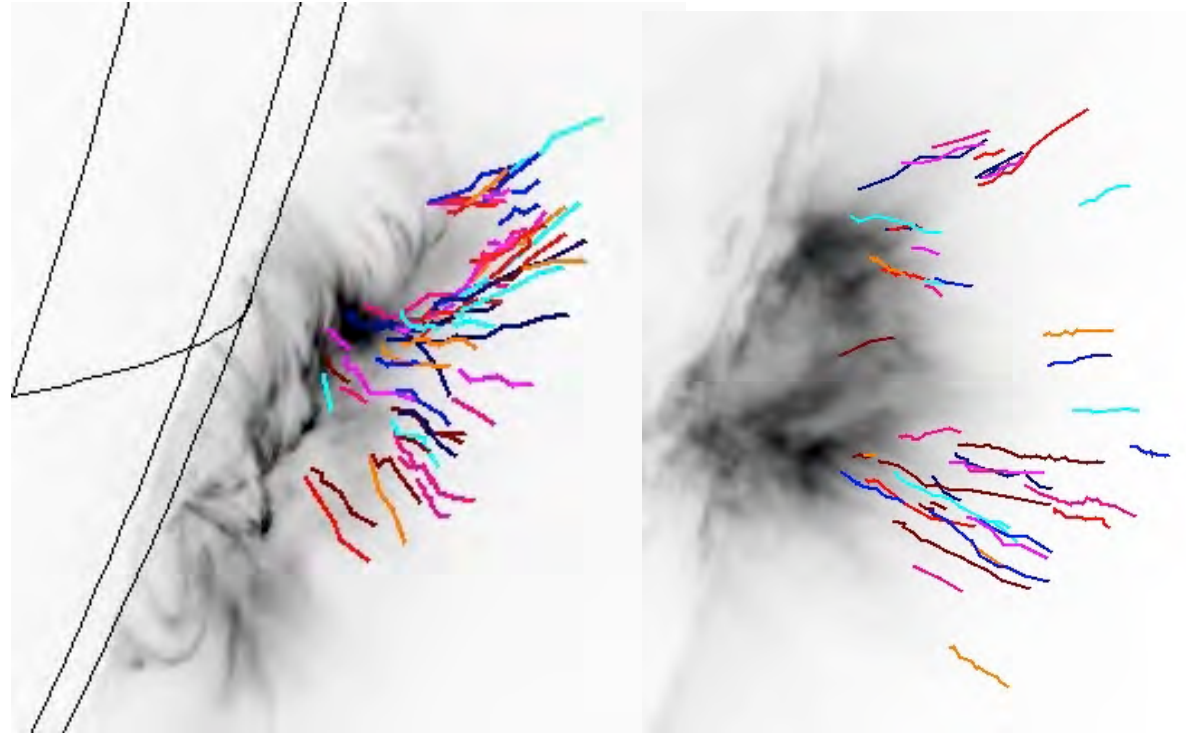
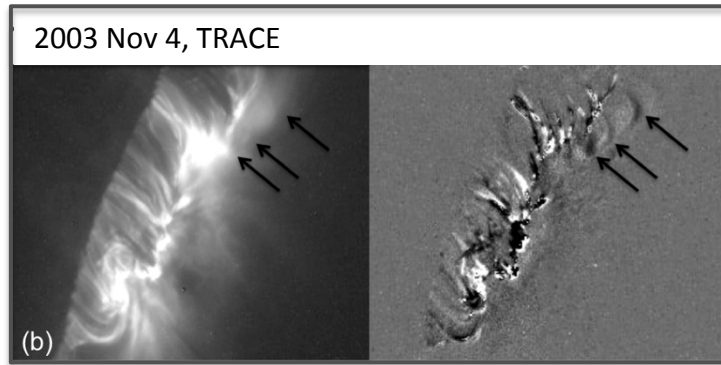
- Teardrop-shaped **voids** observed to travel sunward through the bright, hot fan extending outward along the spine of developing post-flare arcades.
- Observed with high-temperature instrumentation (EUV, X-ray) & white-light coronagraph (density)
- **LONG DURATION EVENTS**

Fig 5



# Supra-Arcade Downflowing Loops (SADLs) Observations

Fig 1



# Supra-Arcade Downflowing Loops (SADLs) Observations

Fig 1

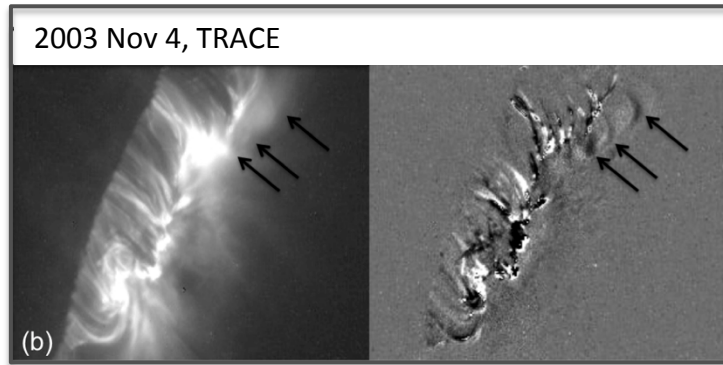
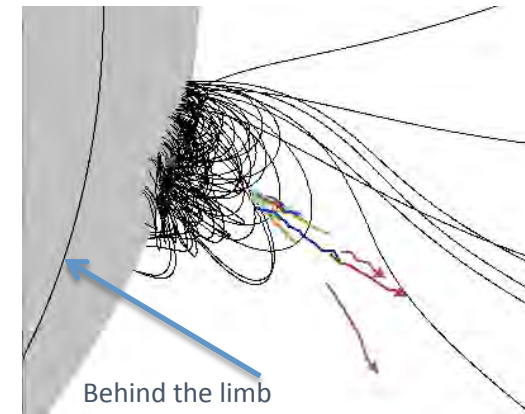
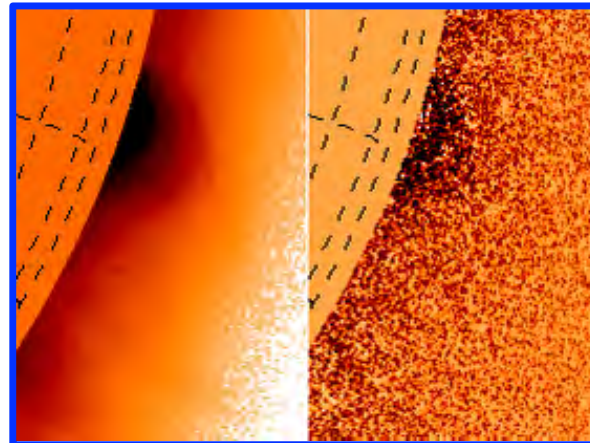
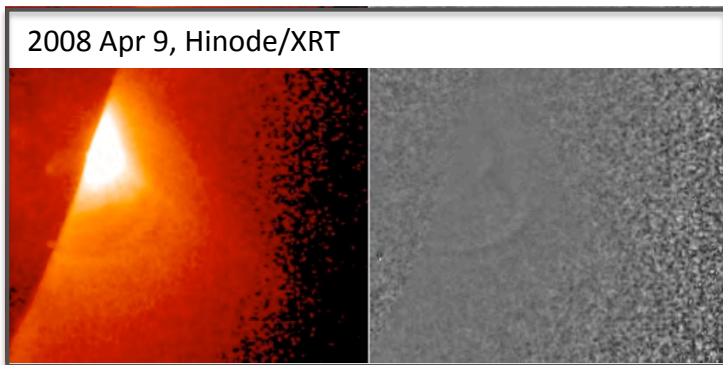


Fig 2





# Supra-Arcade Downflowing Loops (SADLs) Observations

Fig 1

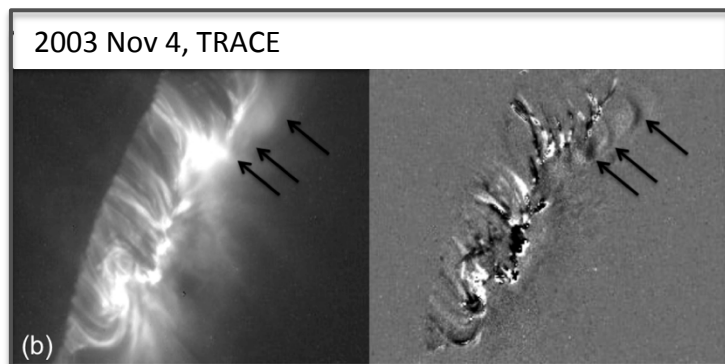
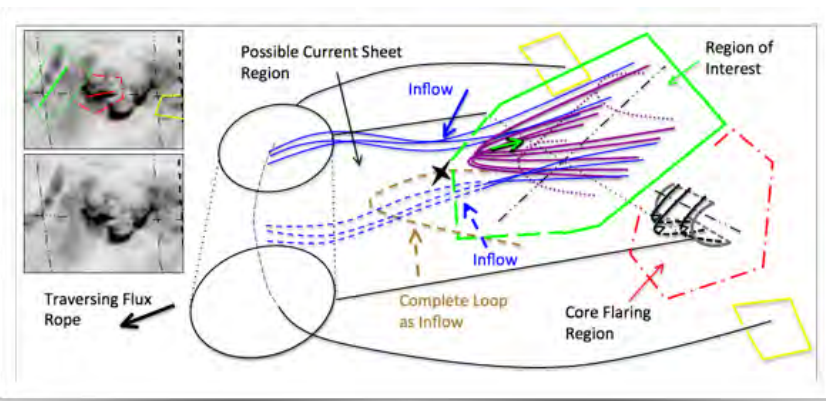
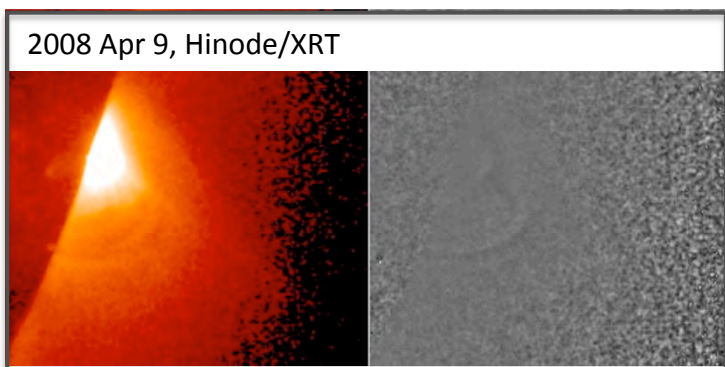


Fig 2



2010 Nov 3, SDO/AIA

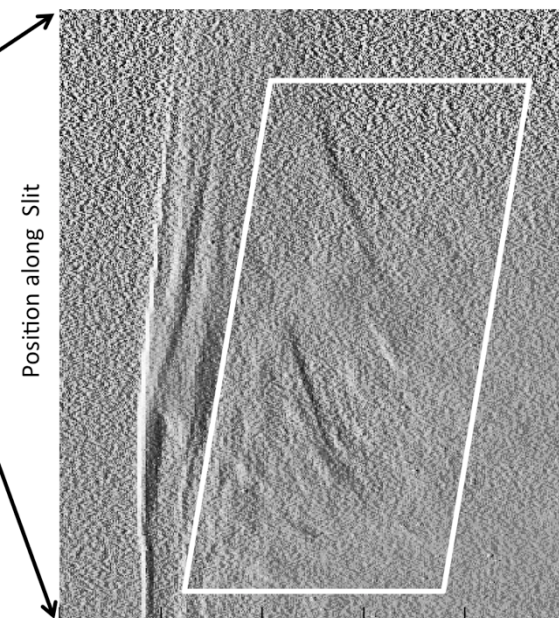
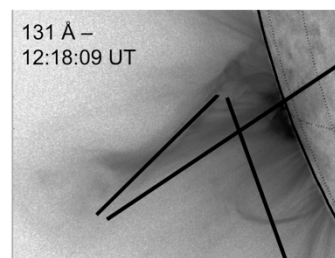


Fig 3

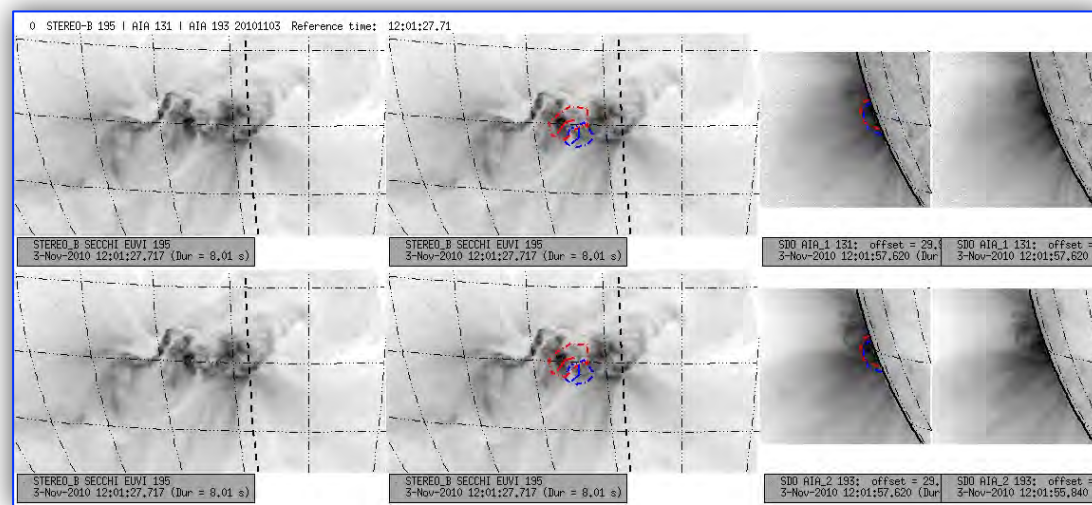


Fig 1: Savage & McKenzie 2011

Fig 2: Savage et al. 2010

Fig 3: Savage et al. 2012

# Different from Plasmoid Observations

- Coherent 'bubble' of **emitting** plasma held together by magnetic fields.
- Observed with broadband-temperature instrumentation (EUV, X-ray, Hard X-ray) & white-light coronagraph (density)

## ➤ Magnetic Islands

Fig 1

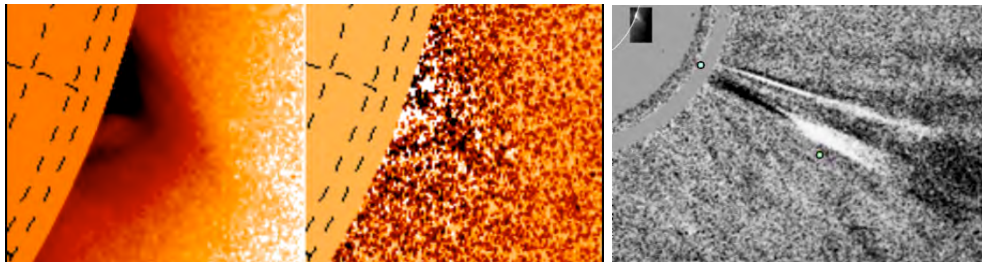


Fig 2

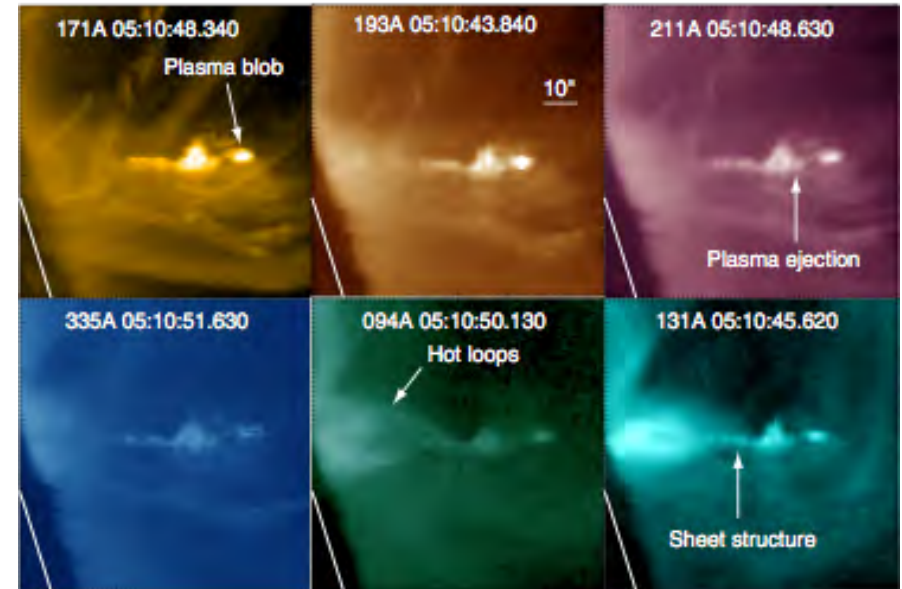
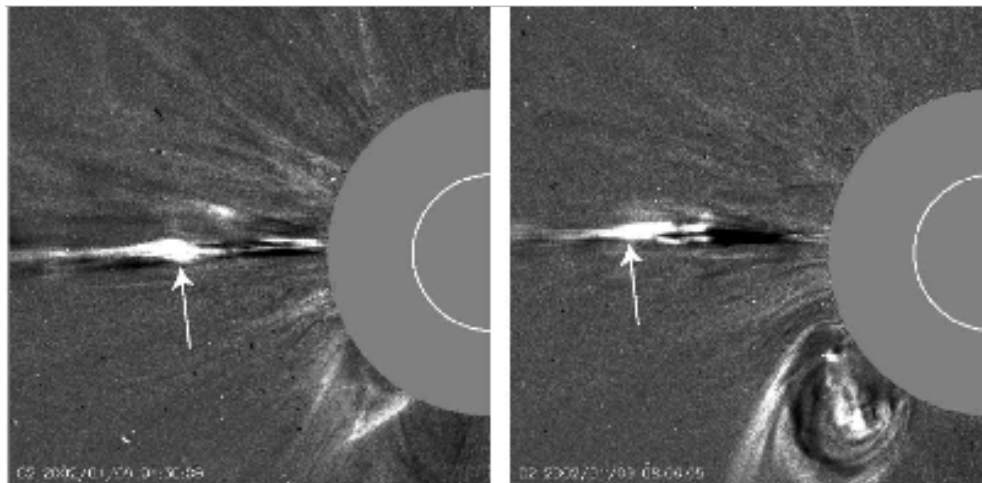


Fig 3

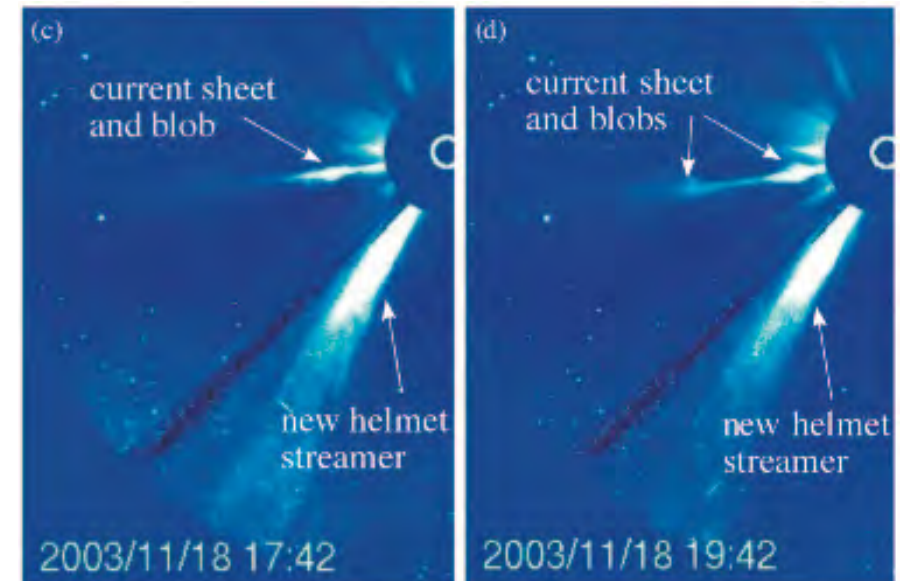


Fig 4

Fig 1: Savage et al. 2010

Fig 2: Ko et al. 2003

Fig 3: Takasao et al. 2012

Fig 4: Lin et al. 2004



# Different from Plasmoid Observations

Fig 1

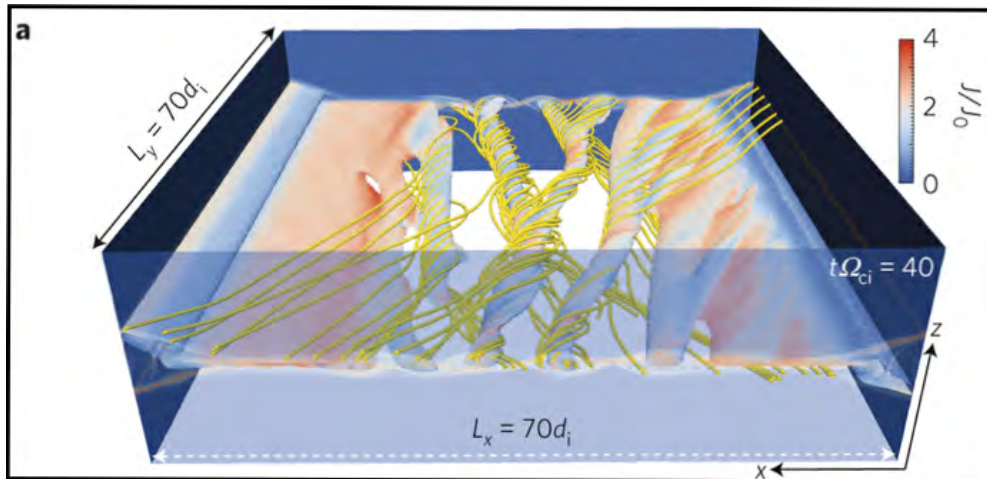
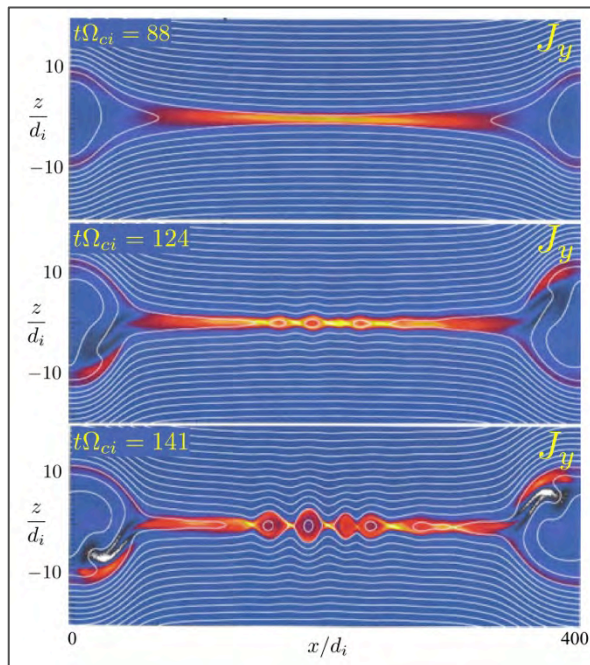
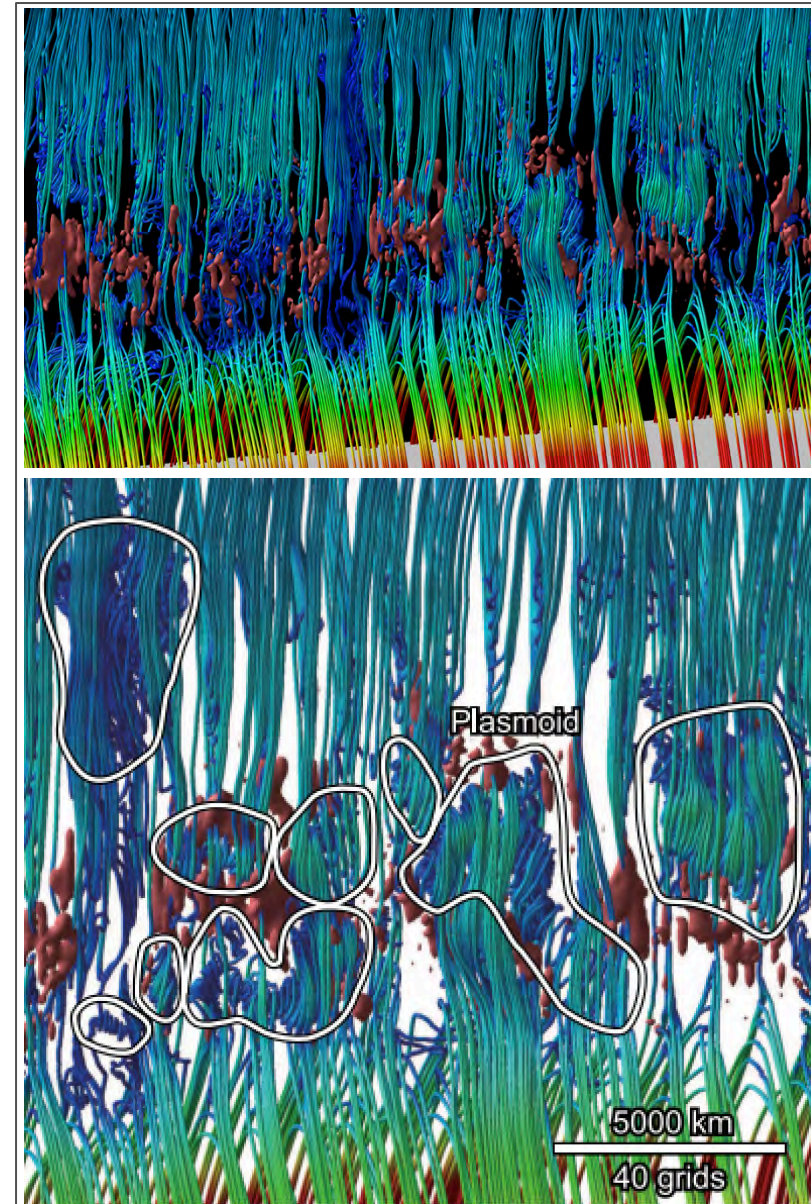


Fig 2



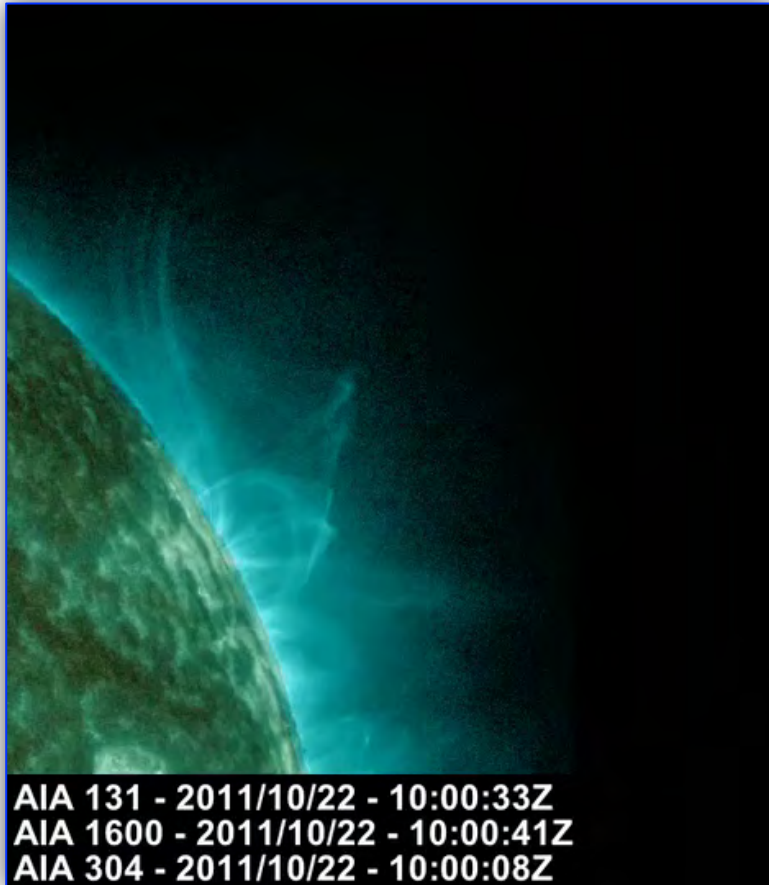
- Thin flux tubes created during the reconnection process across the current sheet.
- Plasmoids a 3-D product of reconnection concurrent to single loop creation.

Fig 3

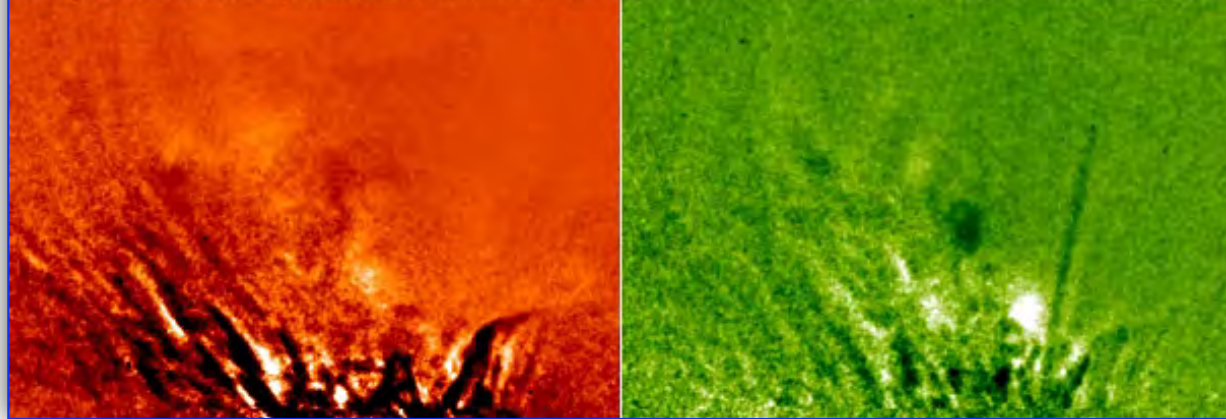




# SADs + SADLs

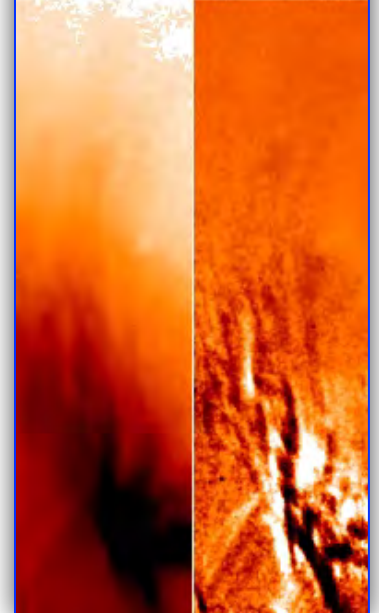


0 AIA 20111022 (RMDIFF) 131 & 193 22-Oct-2011 11:58:09.620



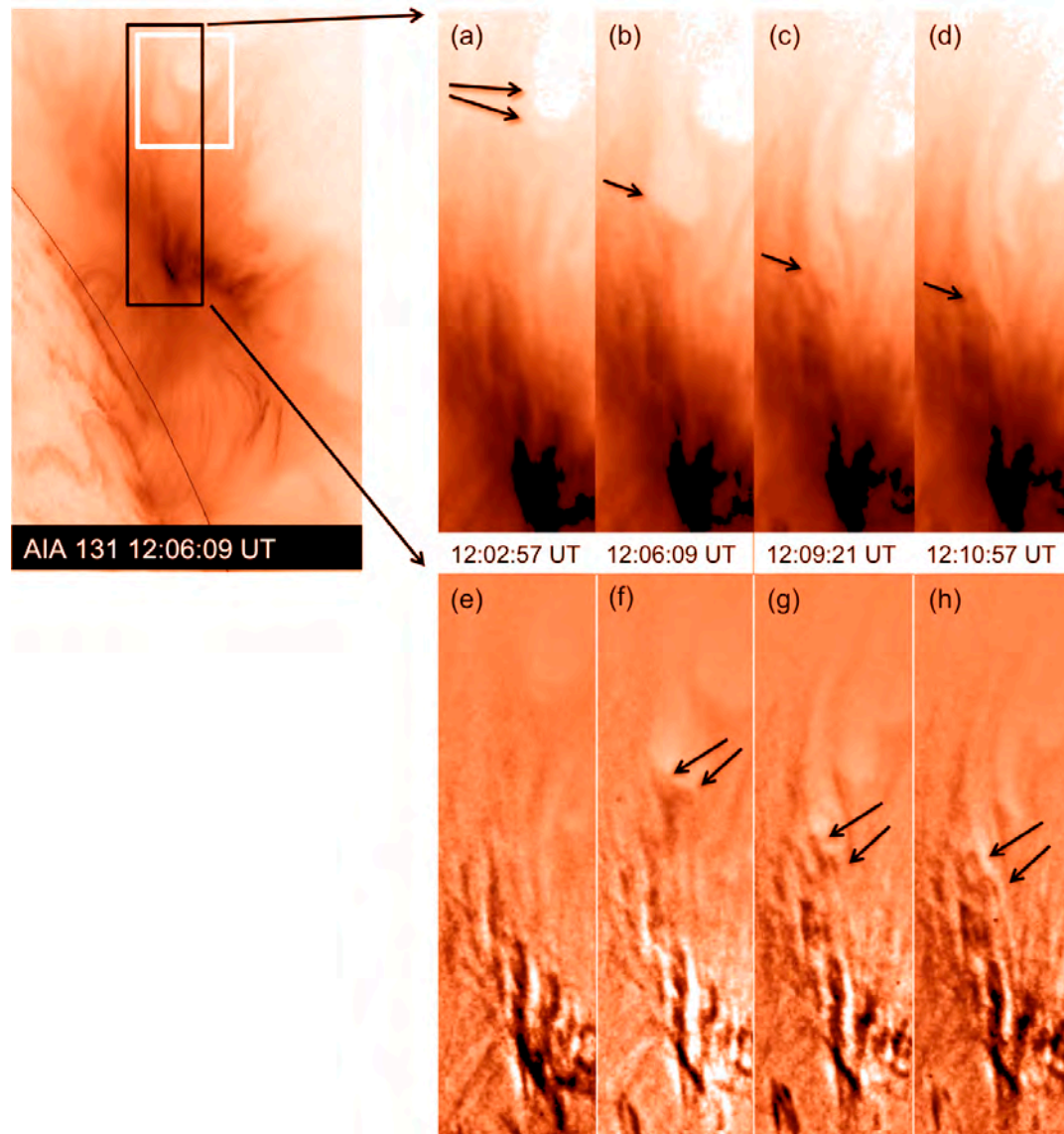
- Hot AIA channels. (2-10 MK)
- Differenced
- Reverse-scaled

0 AIA 20111022-131 11:58:09.6



# SADs + SADLs

Fig 1

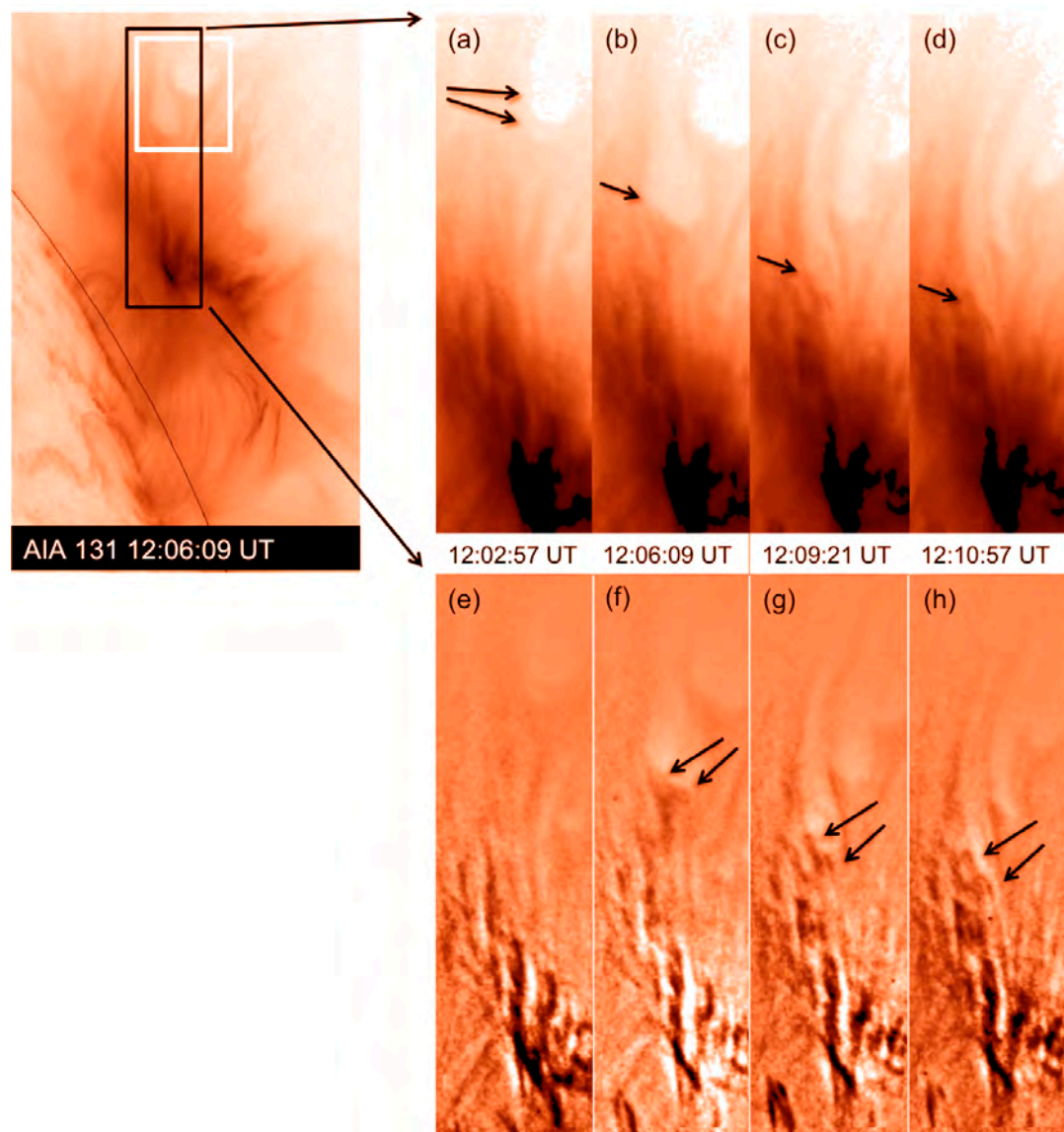


- SADs appear to be voids created by loops (SADLs) shrinking through the fan plasma.



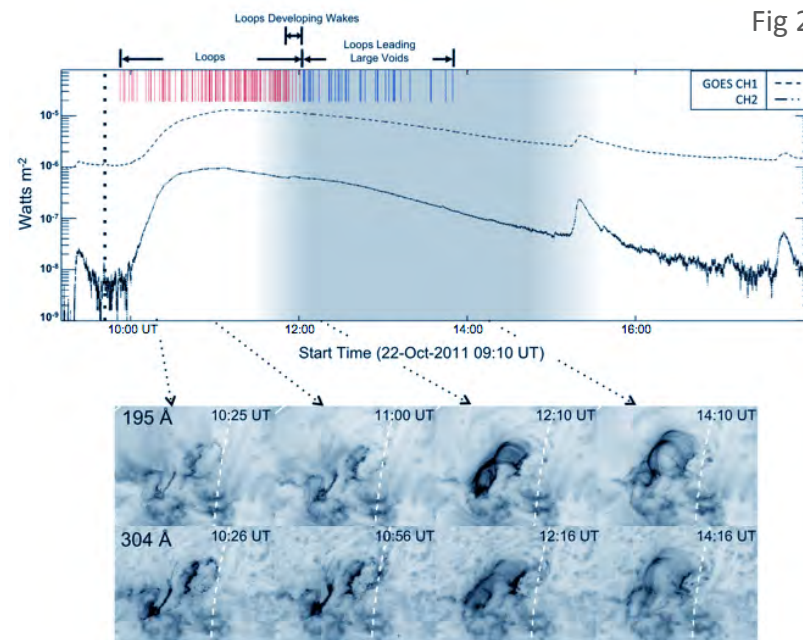
# SADs + SADLs

Fig 1

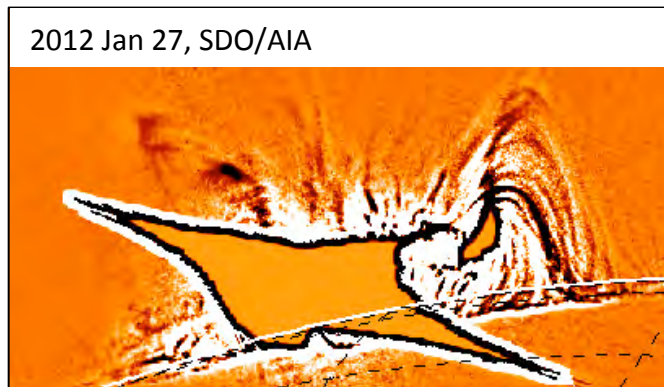
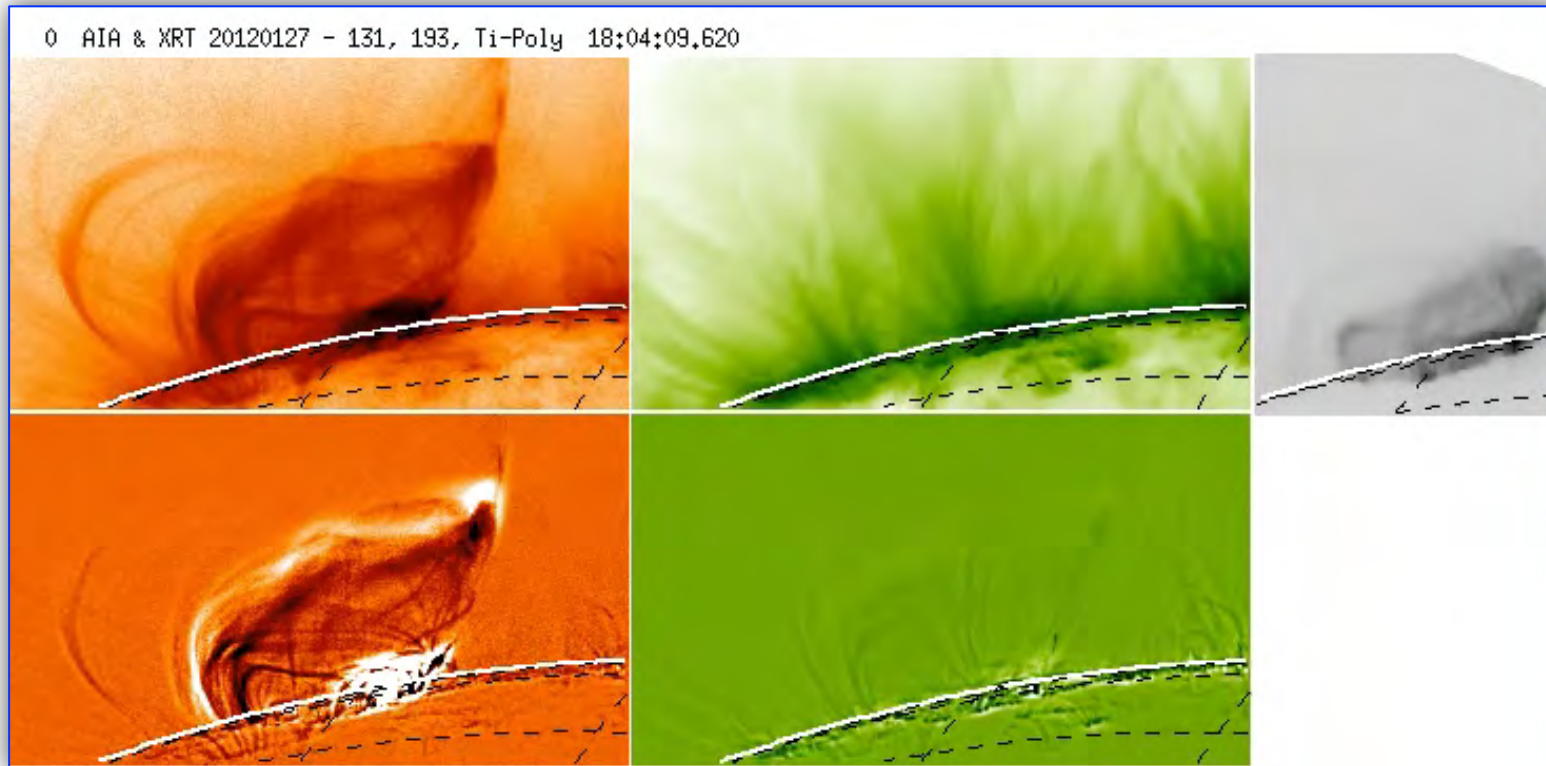


- SADs appear to be voids created by loops (SADLs) shrinking through the fan plasma.

Fig 2



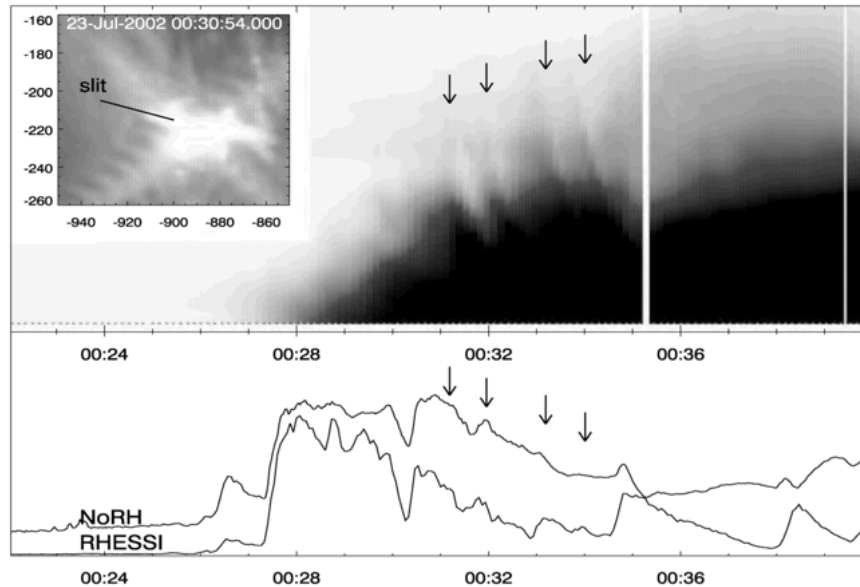
# Supra-Arcade Downflowing Loops (SADLs) Observations



# Particle Acceleration & Heating

RHESSI + TRACE

Fig 1



VLA + AIA + RHESSI

Fig 3

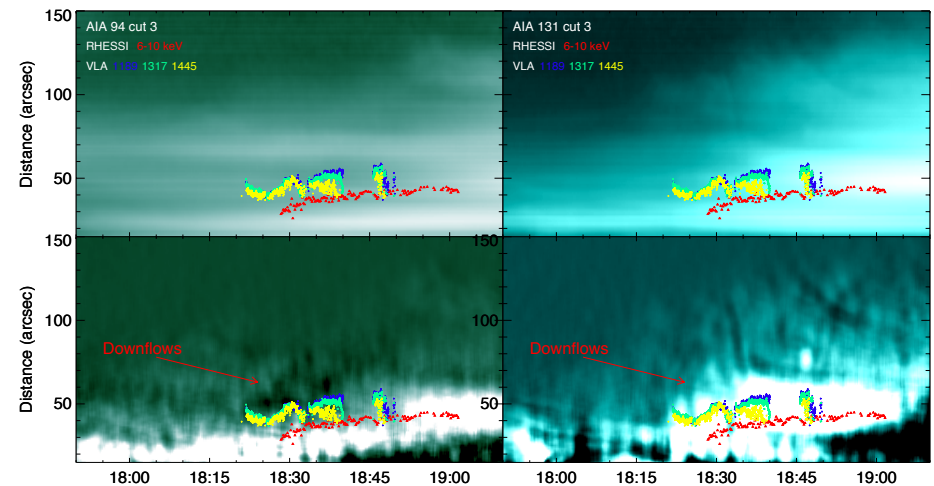
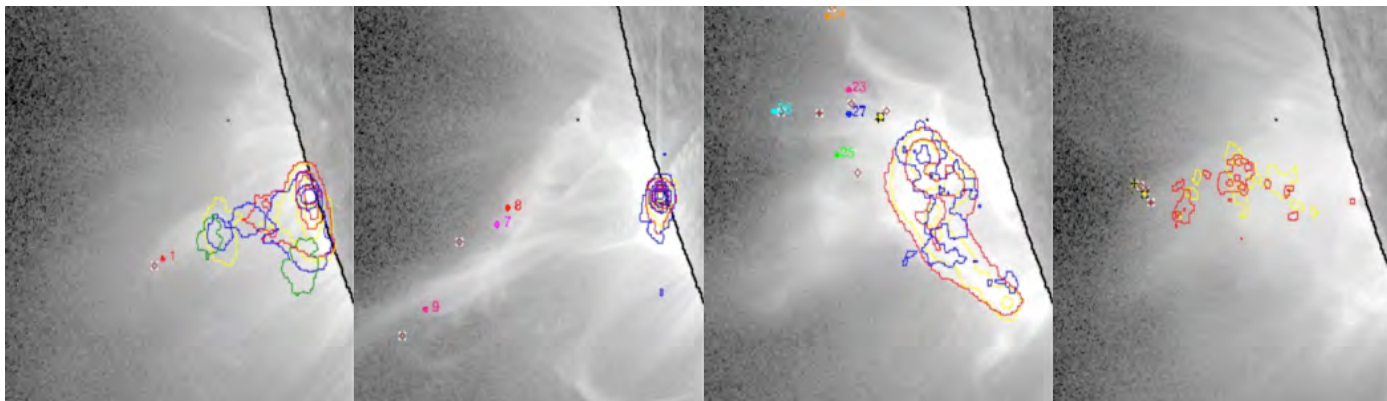


Fig 2



Savage – 2010 Nov 3 flare

RHESSI + AIA



# Diagram Models

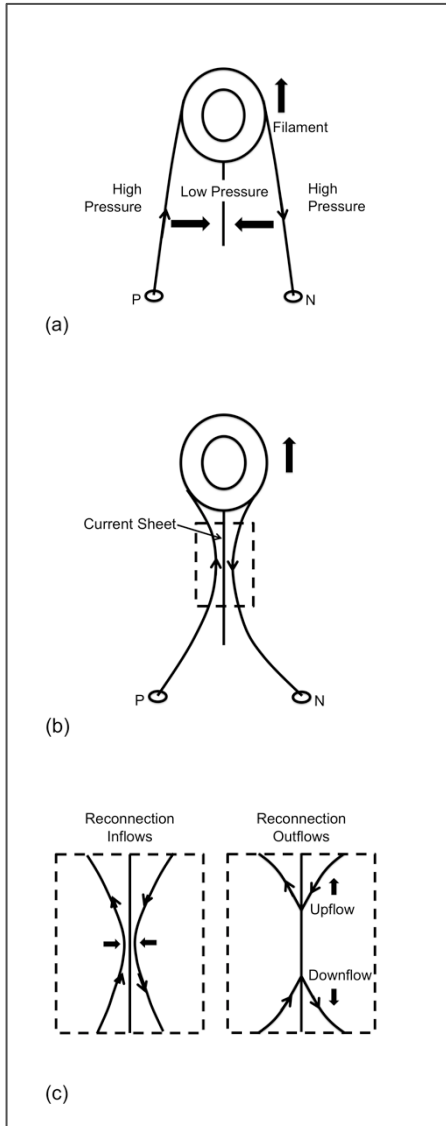


Fig 1

Fig 2

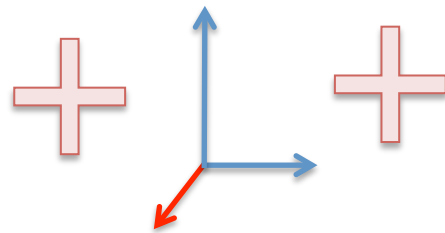
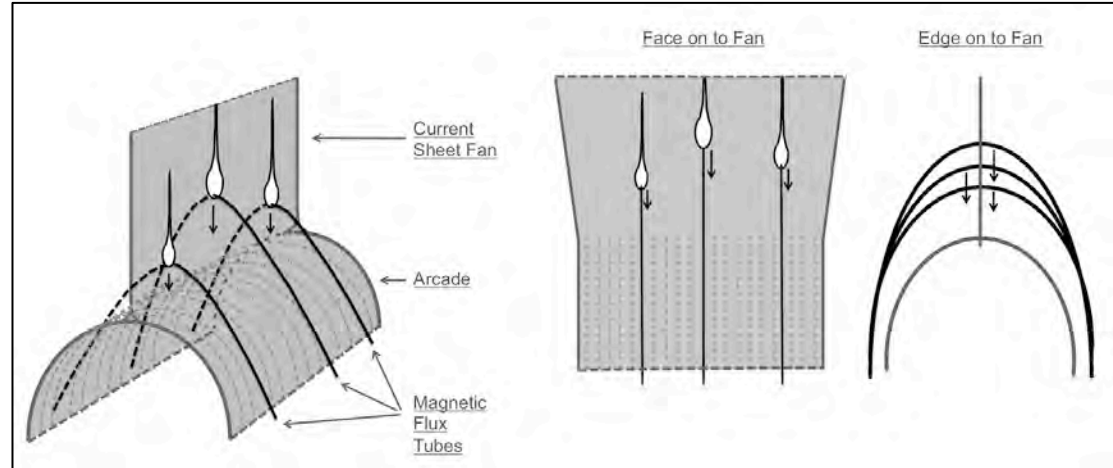


Fig 3

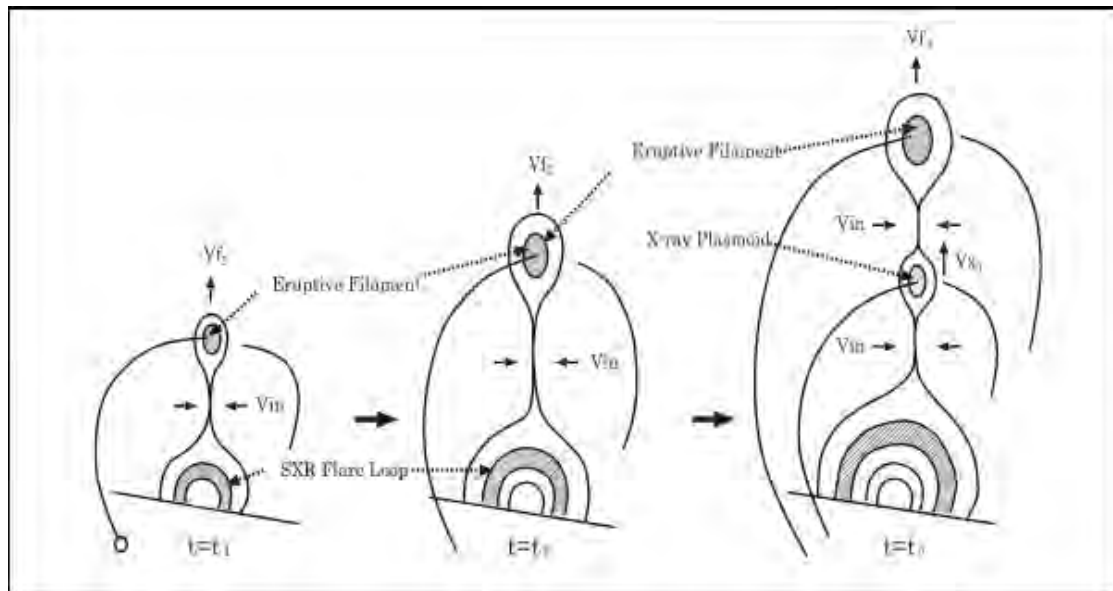


Fig 3: Ohyama & Shibata 2008

Fig 1, 2: Savage et al. 2012

# 3D is Pivotal

Fig 1

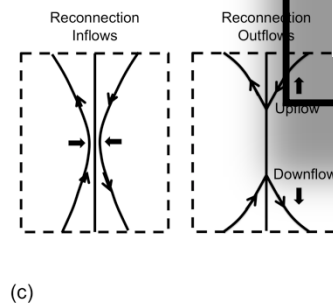
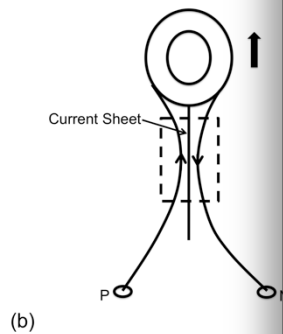
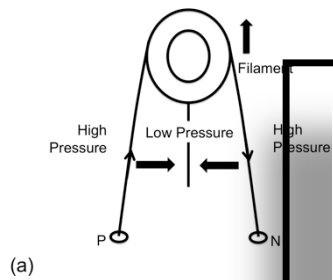
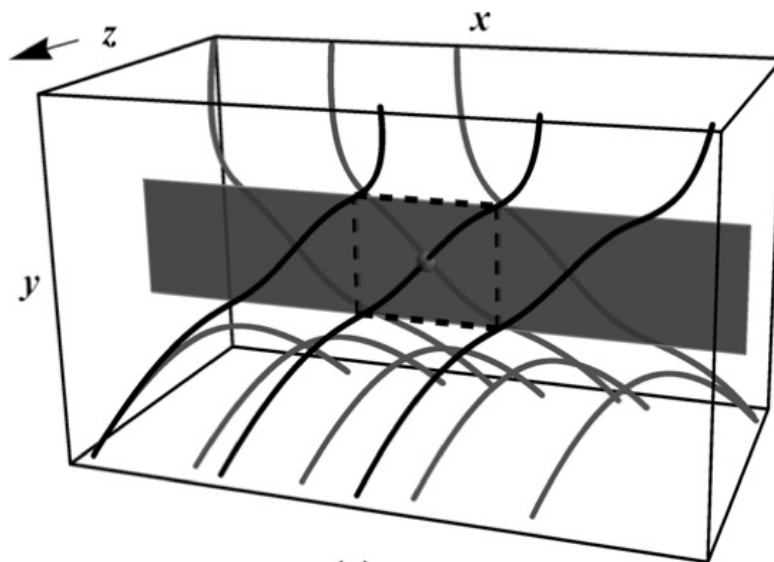
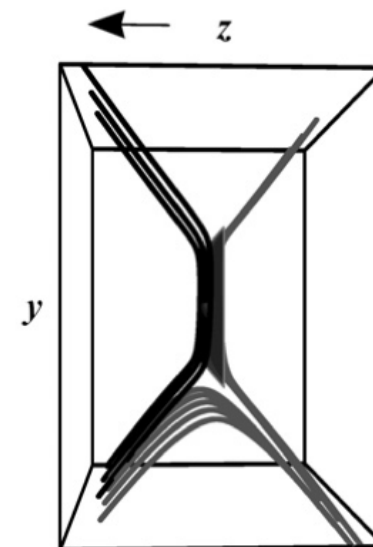


Fig 2



(a)



(b)

Face on to Fan

Edge on to Fan

Current Sheet Fan

Fig 3

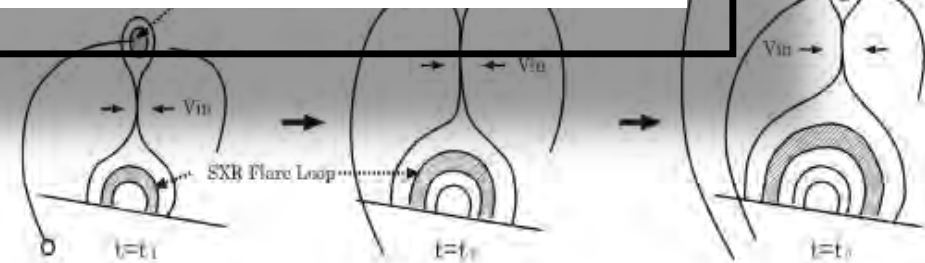
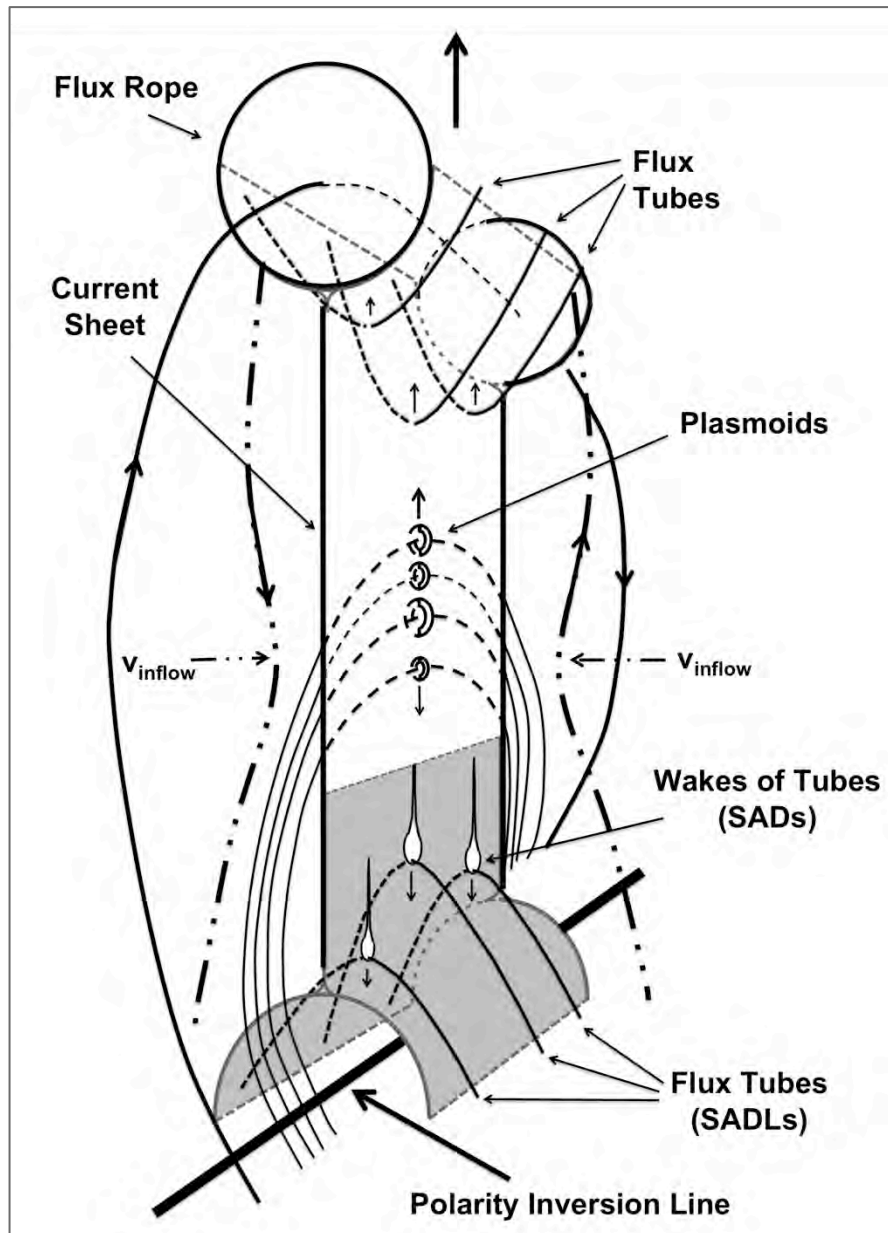






Fig 1



- Basic reconnection scenario, post initial flux rope formation and release.
- General organization of the magnetic field of the various components (SADs, SADLs, plasmoids).
- Field lines reconnect across the current sheet to form outflowing flux tubes while plasmoids form along the current sheet.
- SADs are formed as the flux tubes (SADLs) retract through hot plasma in the fan (*otherwise, only SADLs are observed*).



## Strong potential analogy with magnetotail substorms

Fig 1

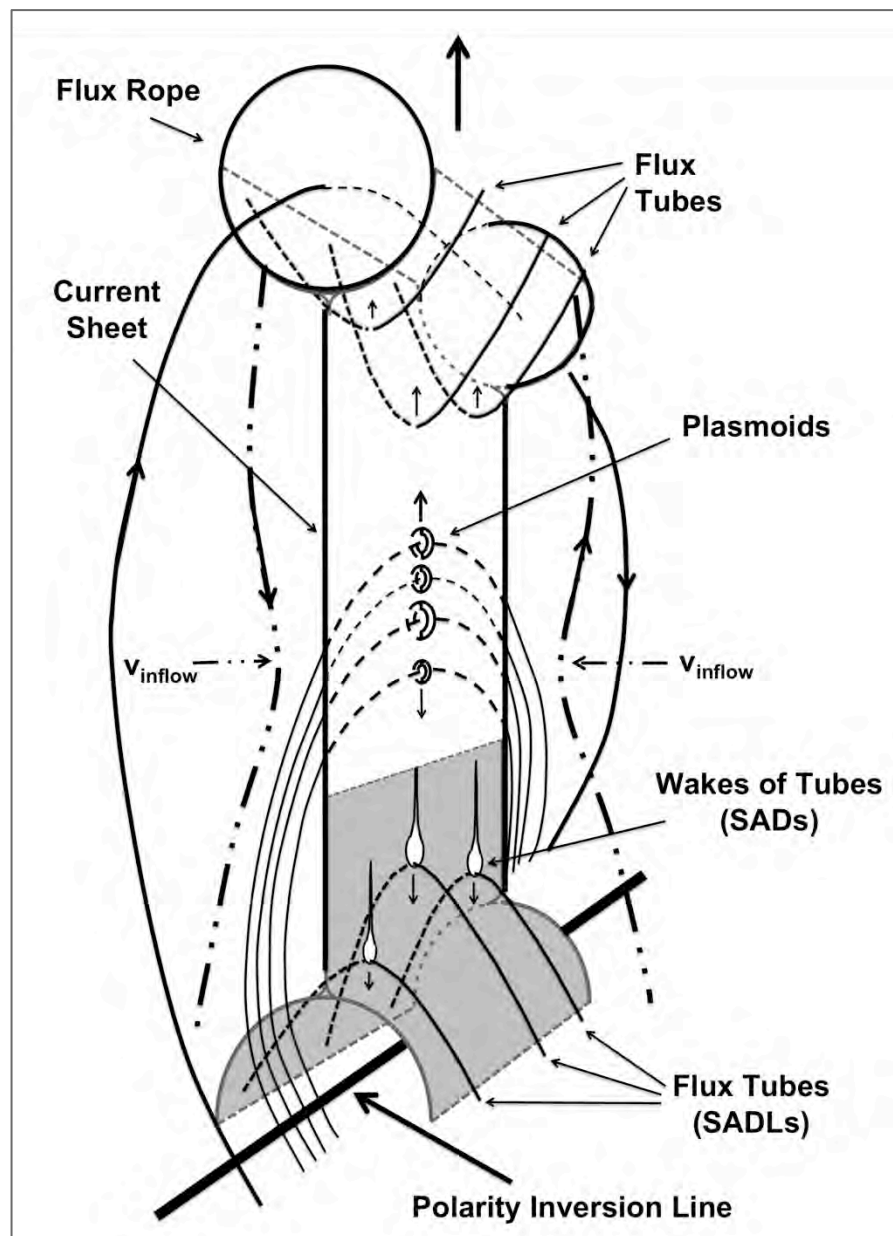
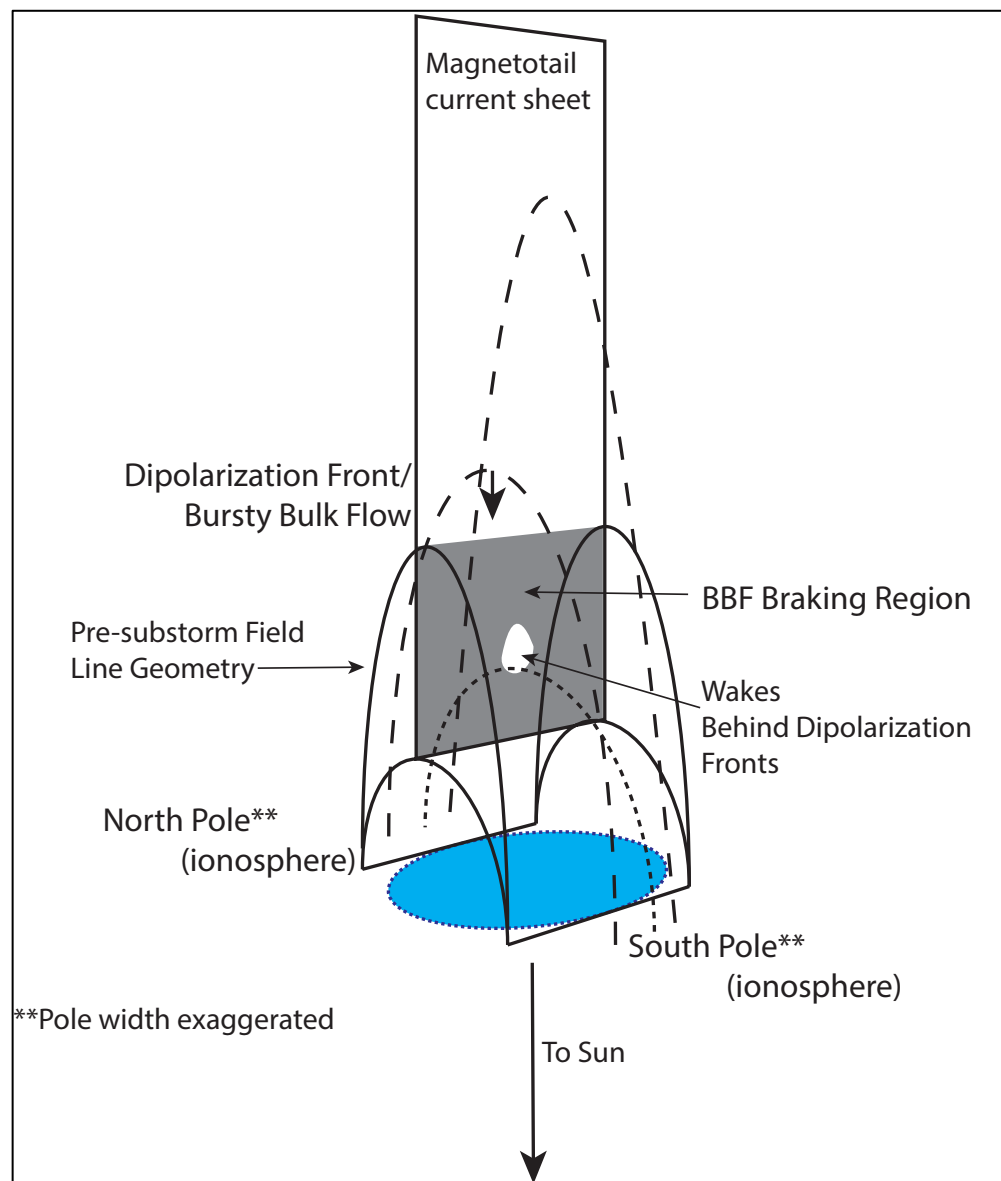


Fig 2



# Using THEMIS for comparison to *in situ* data

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Substantial density drop following the dipolarization event!

# Model Constraints

**OBSERVED TEMPERATURE AND DENSITY ALWAYS LOWER THAN FAN**

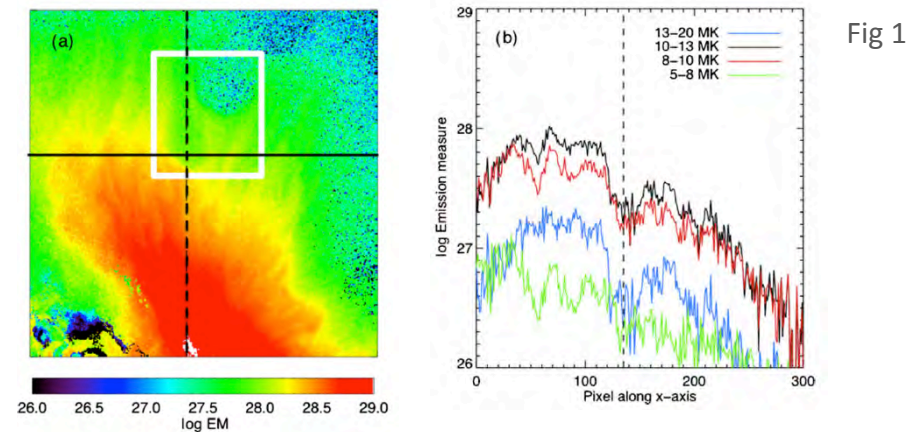


Fig 1

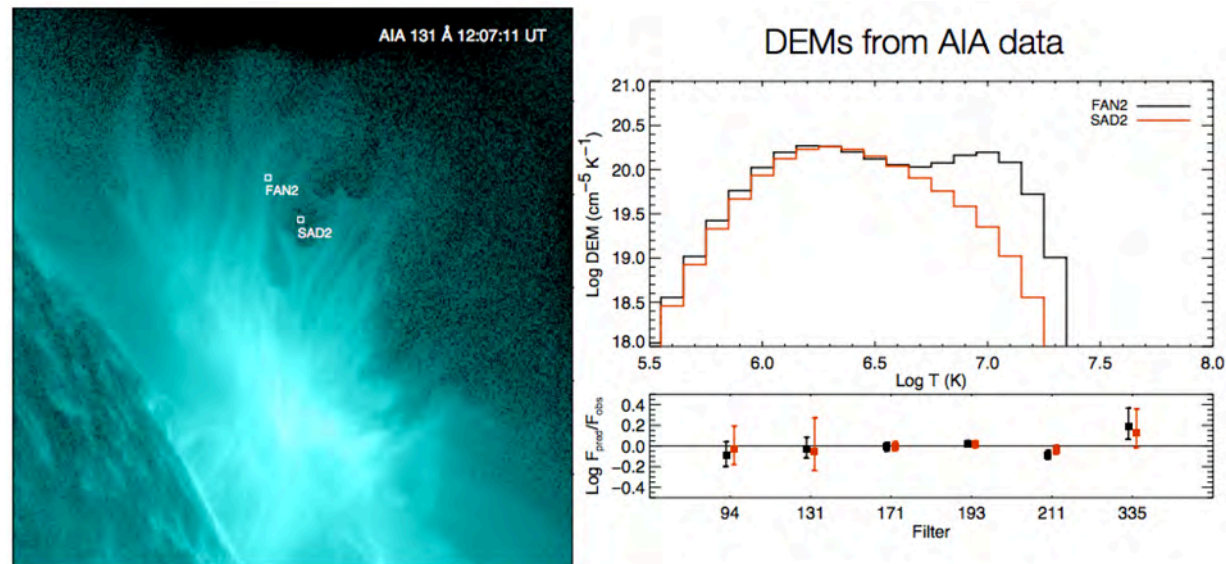
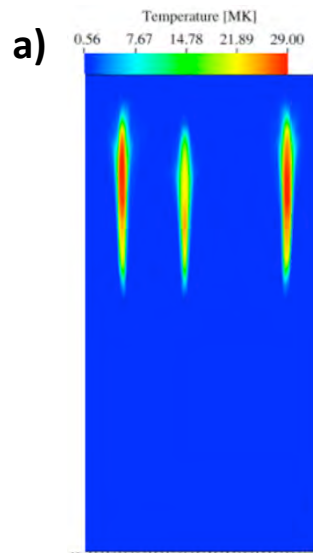


Fig 2

# Model Simulations

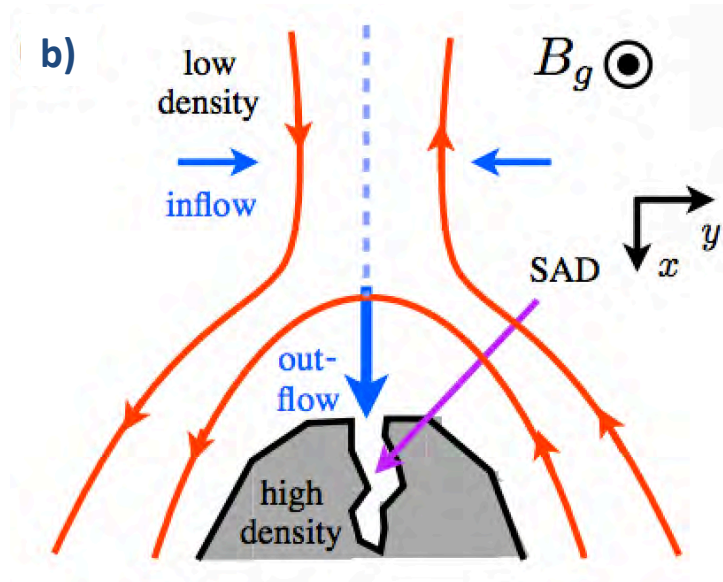


Pressure pulse + MHD wave

( $T \gg \text{fan}$ )



Too hot with respect to the surroundings

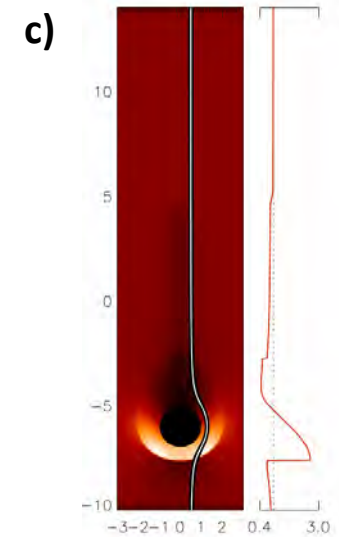


Reconnection outflows

( $T \sim < \text{fan}$ )



Incorrect geometry with respect to observations



Peristaltic pumping

( $T \sim < \text{fan}$ )

Incomplete, feasible;  
Difficult to match to  
observations

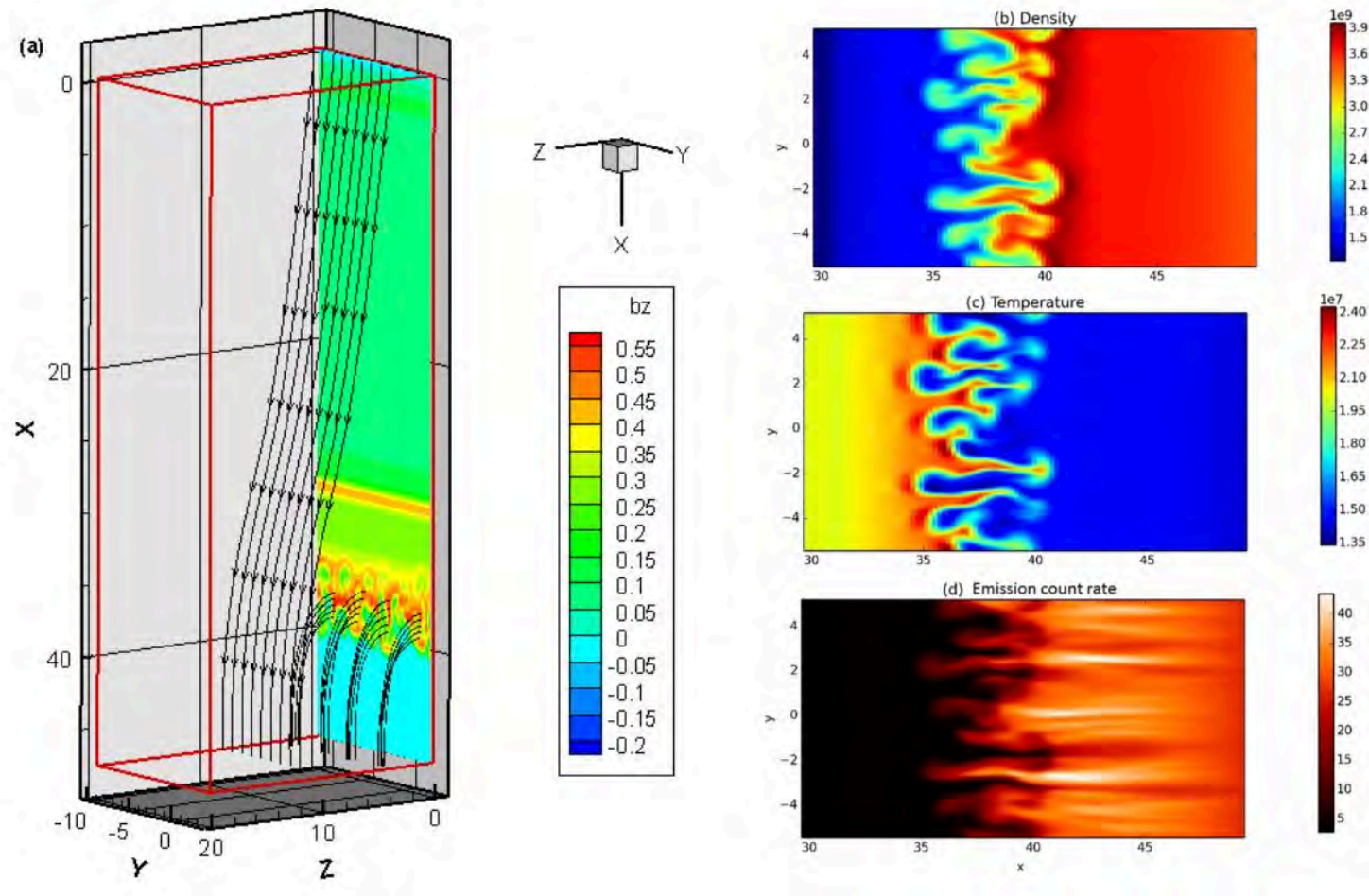
Fig 1: Cecere et al 2012

Fig 2: Cassak et al 2013

Fig 3: Scott et al 2013



# Model Simulations



Rayleigh-Taylor Instabilities behind retracting flux tubes ( $T > \text{fan}$ )

Too hot with respect to the surroundings

BUT

Best match to observations to date (3D!)  
although early in development

# SADs in the Extended Corona

Fig 1

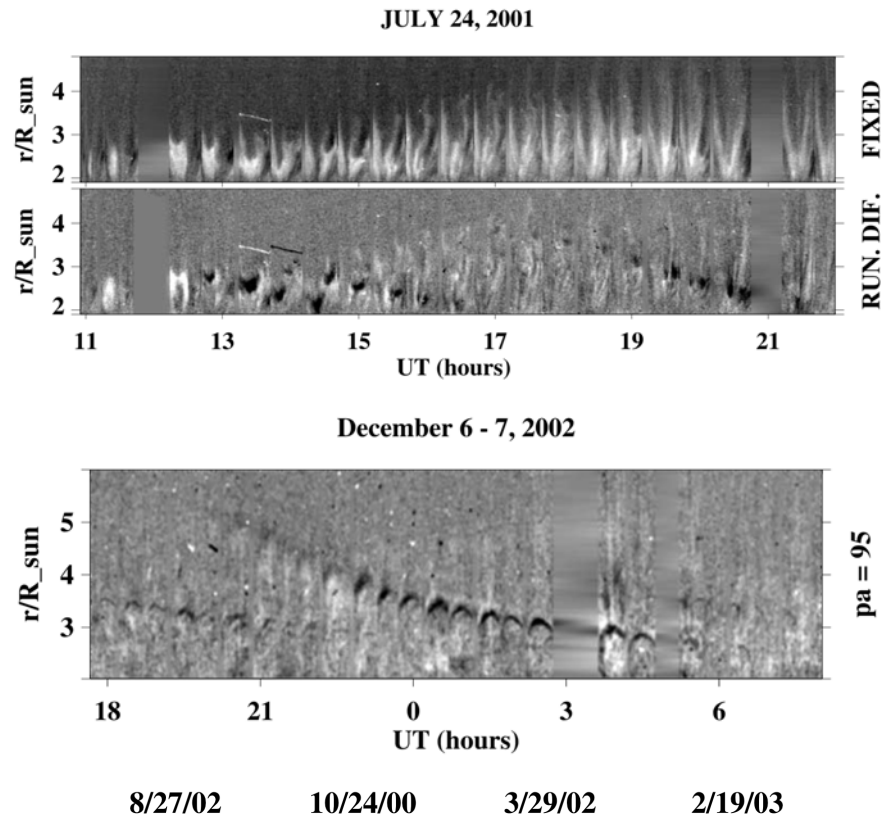
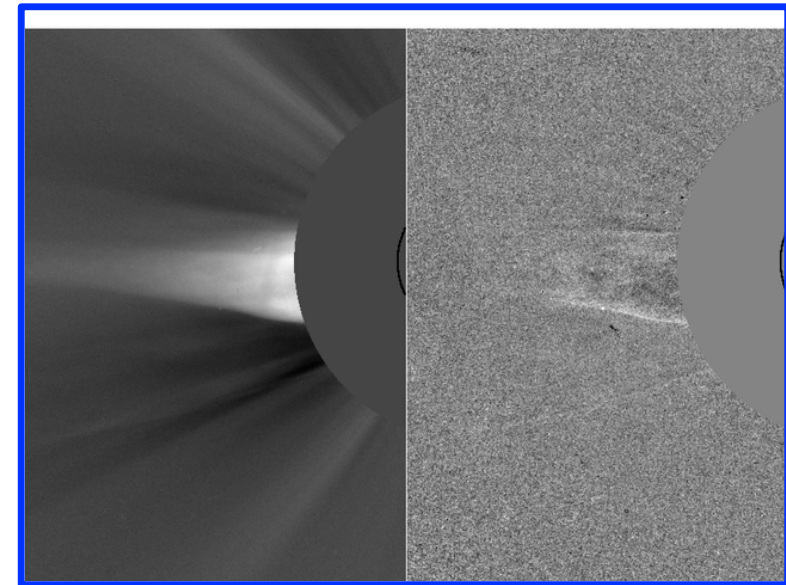
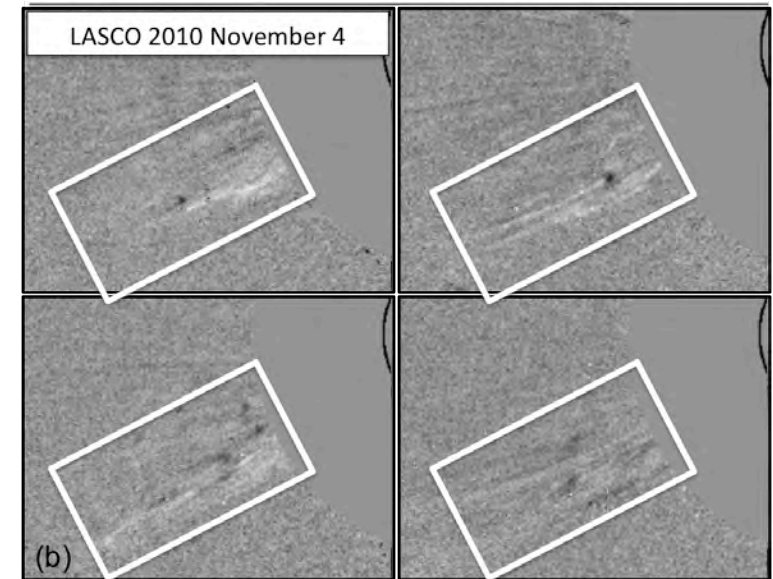
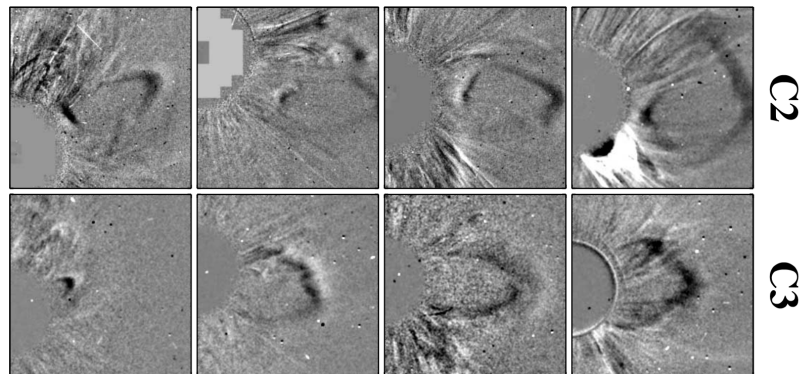


Fig 2



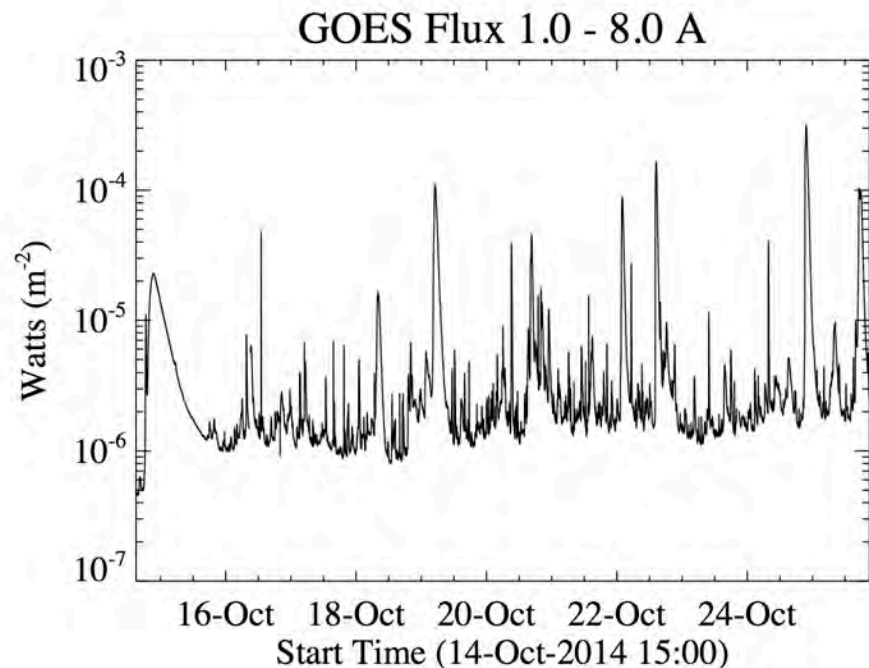
Go see Matthew West's talk Friday @ 11:45

# SADs in the Extended Corona...

SADs in the lower corona are typically observed well after reconnection has occurred.

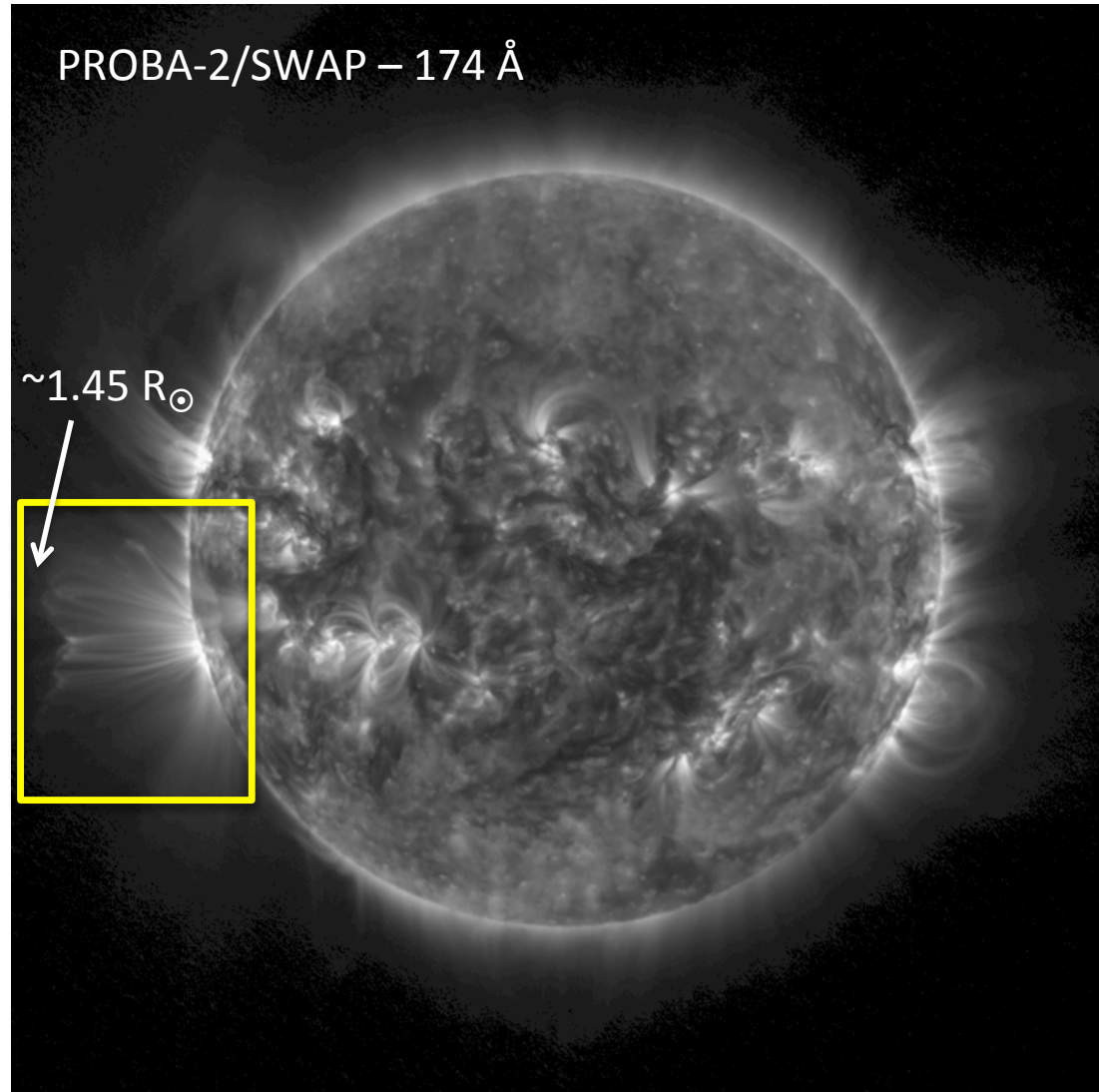
In the extended corona, we are better able to observe the migrating reconnection sites.

Coronagraphs allow us to see reconnection develop behind the CME while looking directly at the density.



“Giant Arches” Flare – 2014 Oct 14

Fig 1





# SADs in the Extended Corona...

LASCO C2

PROBA-2/SWAP

AIA 131 Å

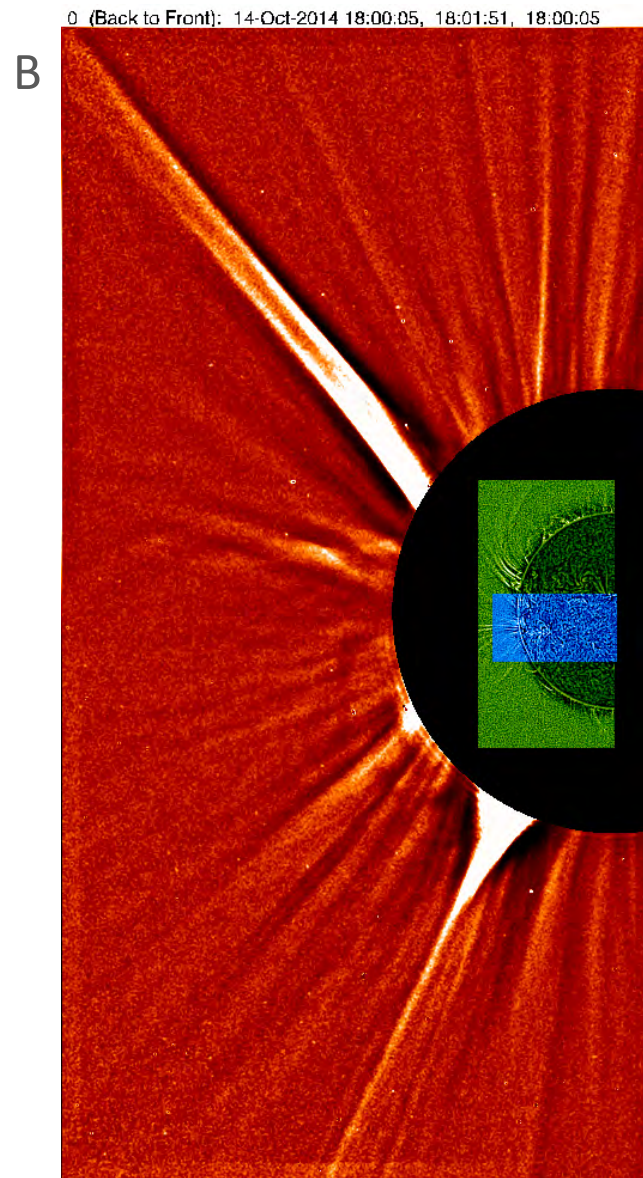
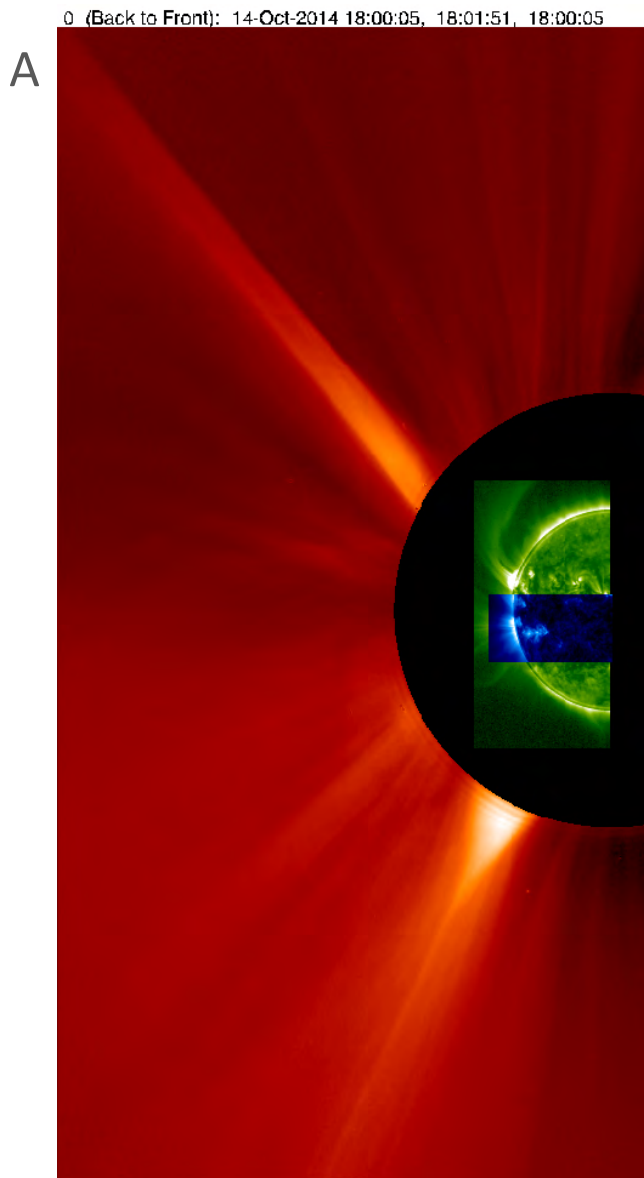
A: Flattened from a year's  
worth of data

Cleaned (cosmic  
rays, background  
stars, planets)

Attenuated disk

B: Smooth-Differenced

- Scaled



# SADs in the Extended Corona...

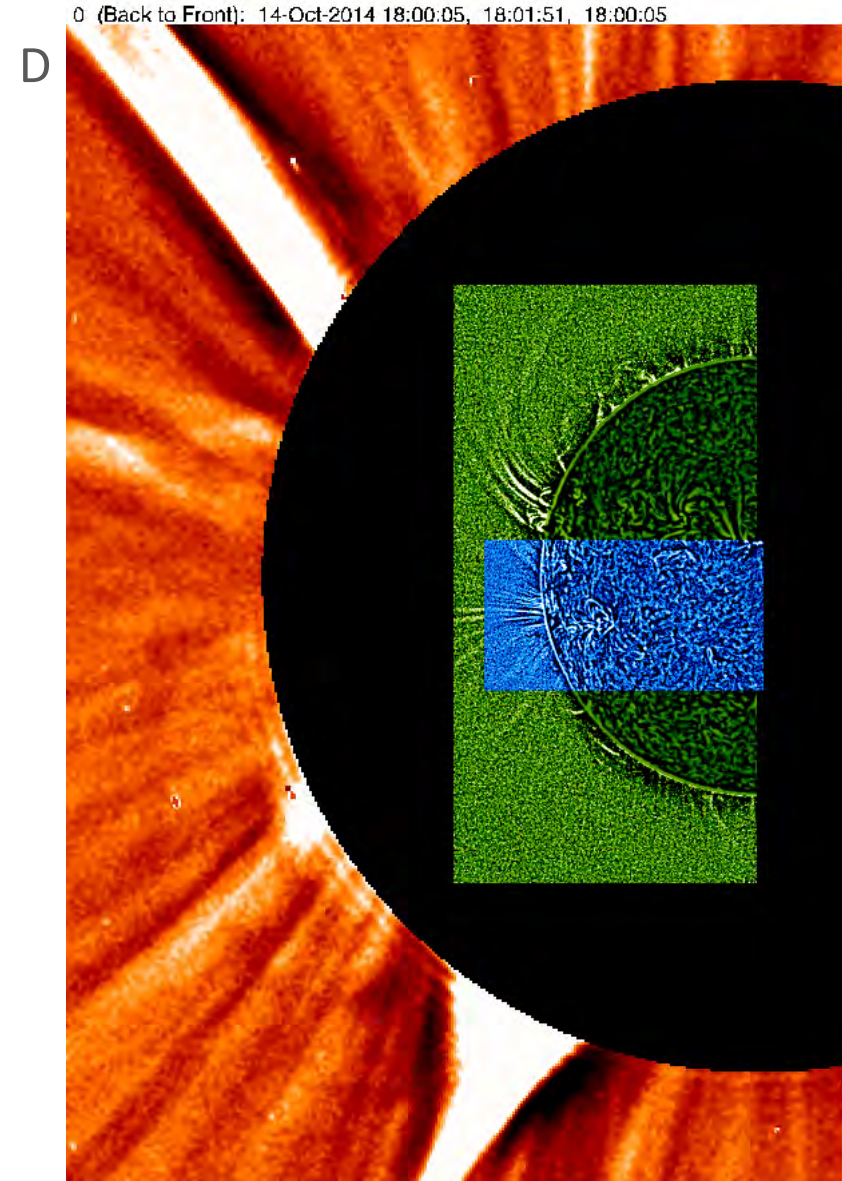
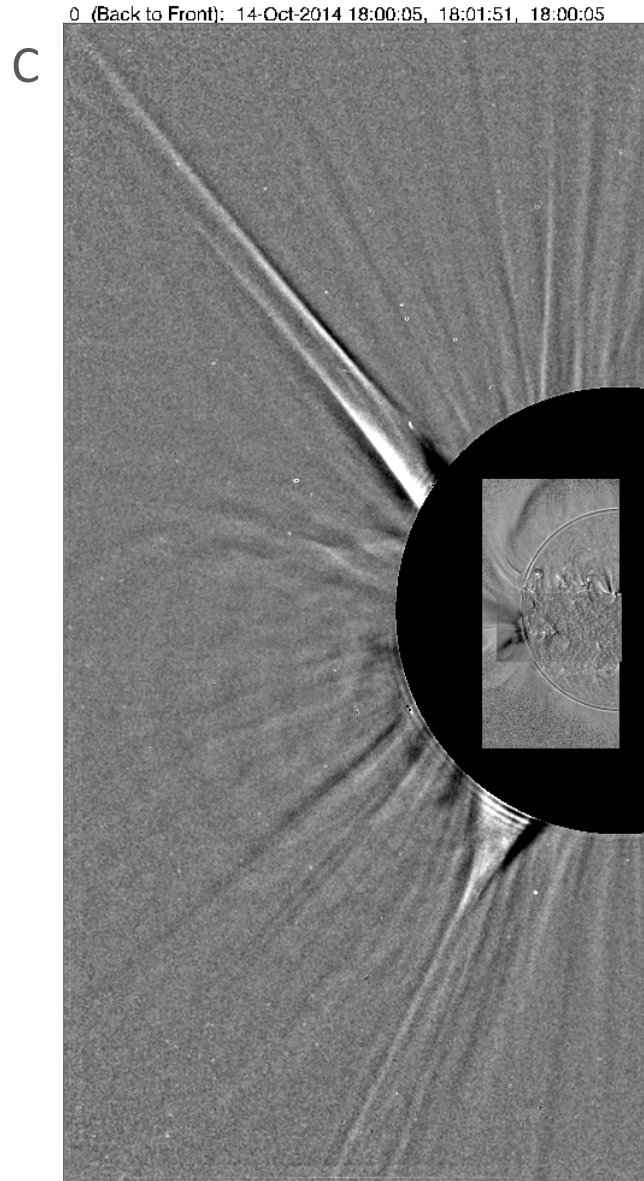
LASCO C2  
PROBA-2/SWAP  
AIA 131 Å

C: Run-Mean-Differenced

D: Smooth-Differenced

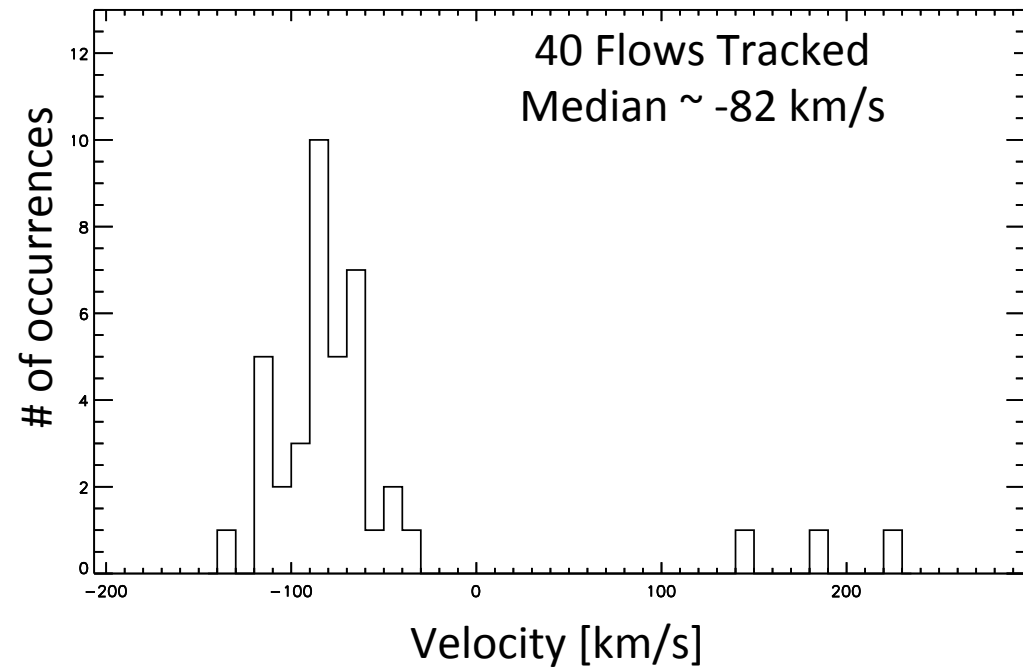
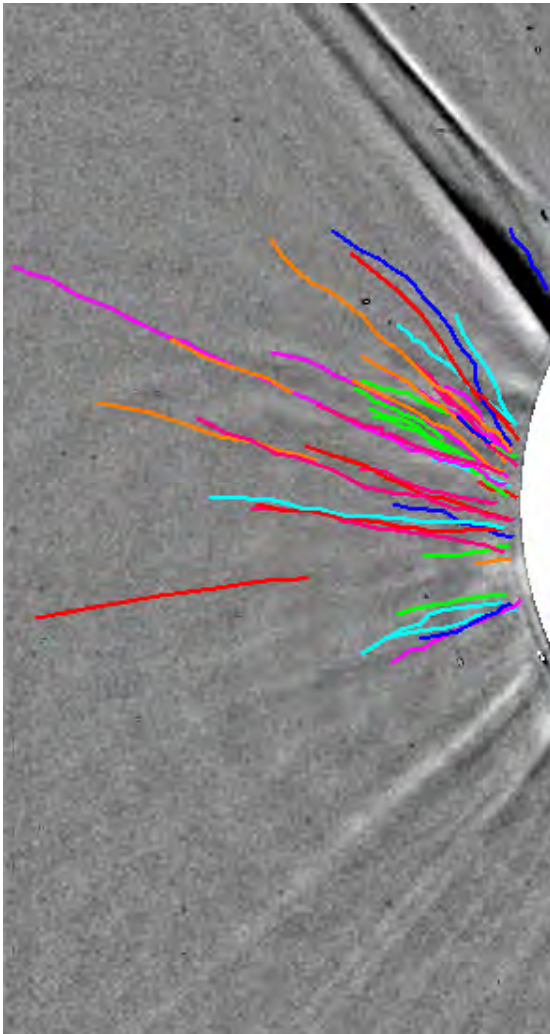
Extracted

- Scaled

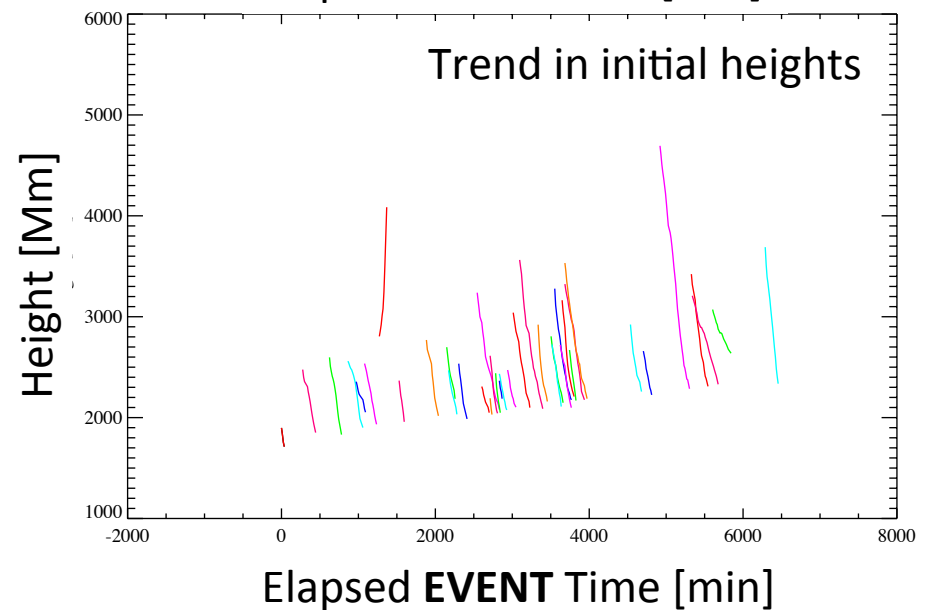
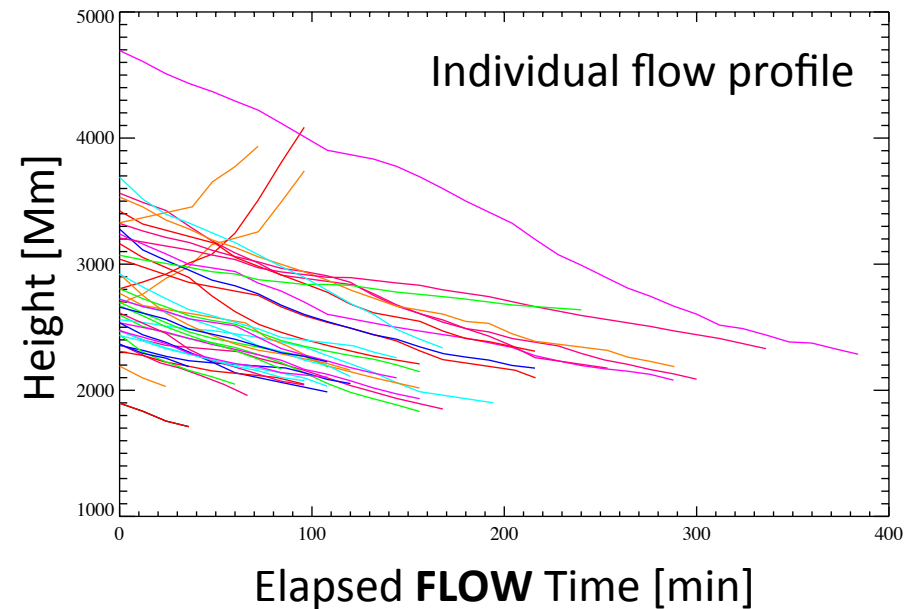
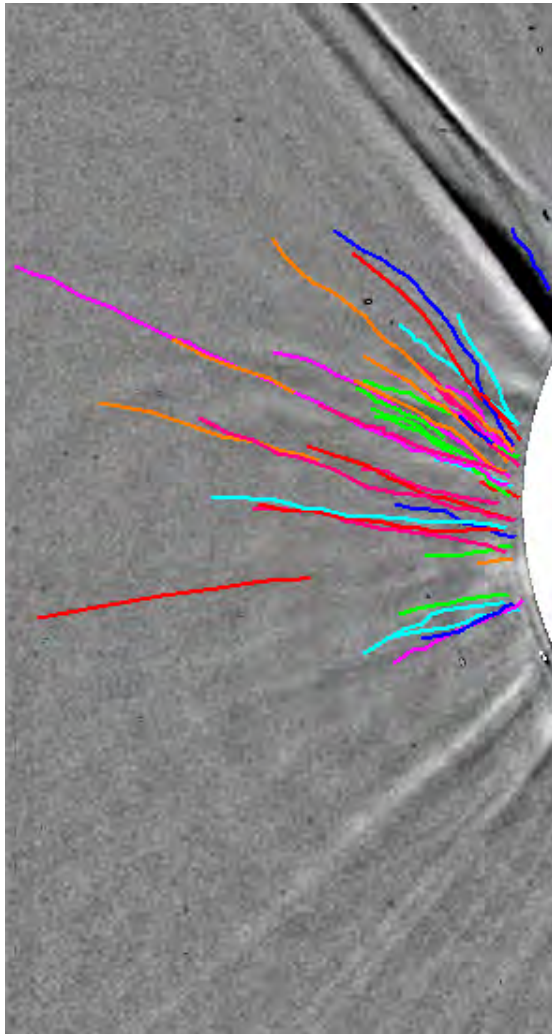




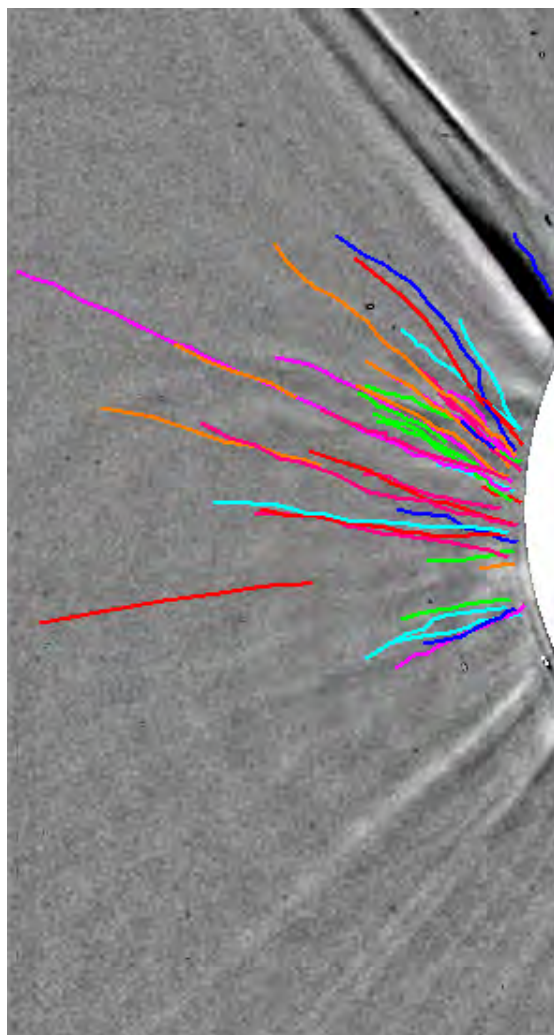
# SADs in the Extended Corona...



# SADs in the Extended Corona...

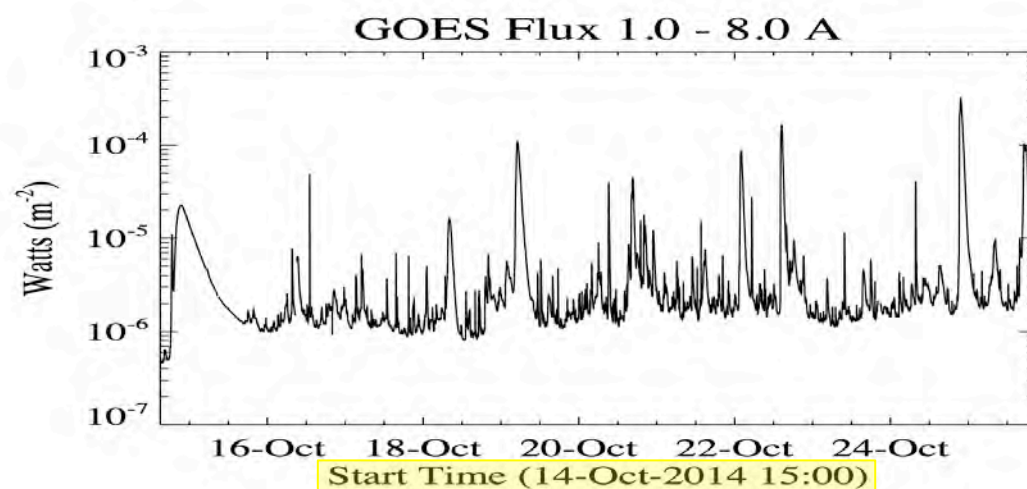
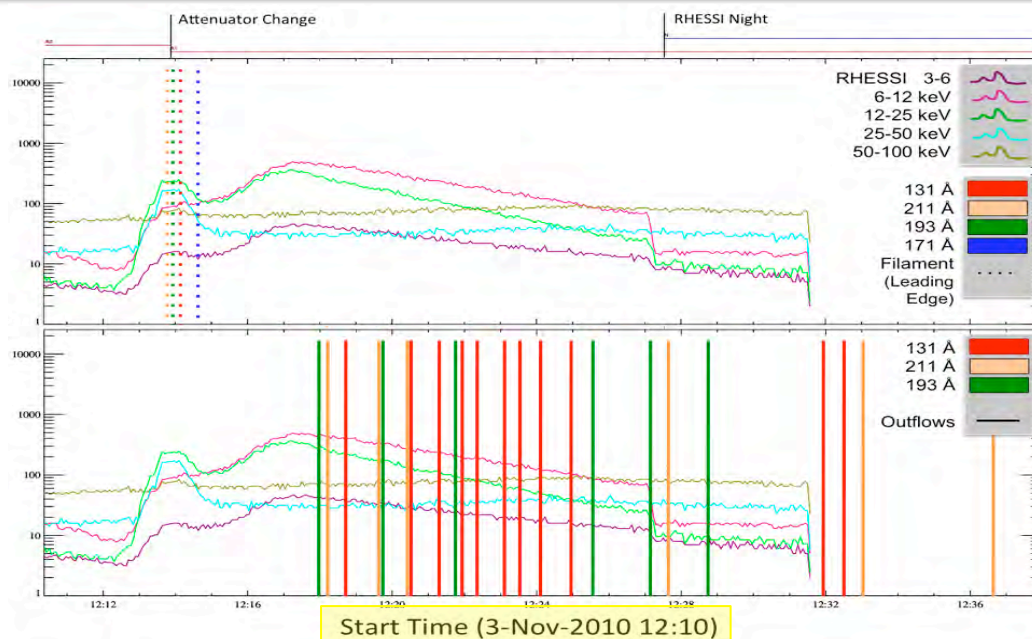


# SADs in the Extended Corona...



## TBD

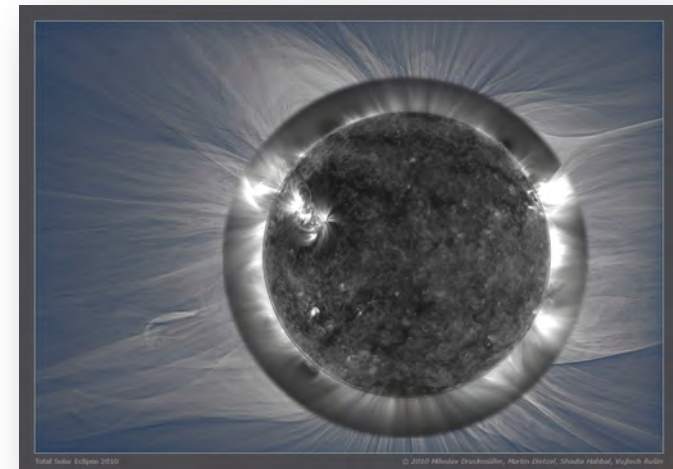
1. Correlate flows directly to lightcurve as done for 2010 Nov 3<sup>rd</sup> event
2. Spatially and temporally correlate RHESSI and Hinode/XRT X-ray contours with outflows.





# Summary & Forward Work

- Continuation of shrinking loops imparts energy into the current sheet long after the flare. Clearly.
  - But for an entire week??
  - Does this happen all of the time?
  - How did this one grow so large?
    - Density stratification? Active region interactions?
- Reconnection is fast and patchy.
- Add Hinode/XRT and RHESSI data (started).
- Do features track between fields of view both ways?
  - Initial work begun. (Some even in LASCO C3.)
- Need for instrumentation to fill the gap in observing the transition corona
  - Important to be in single wavelength
  - Possibly coming to an International Space Station near you....







# An EUV Wide-Field Imager and Spectrometer for the ISS

Leon Golub<sup>1</sup> and Sabrina Savage<sup>2</sup> for the Coronal Spectrographic Imager in the EUV (COSIE) Team

(1) Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, (2) Marshall Space Flight Center (MSFC), Huntsville, AL



## Abstract

The Coronal Spectrographic Imager in the EUV, COSIE, combines a wide-field solar coronal EUV imager (EUVC) and an on-disk EUV imaging spectrometer (EUVS). Located on the International Space Station (ISS), the goal of the mission is to enhance our understanding of the dynamics of the Transition Corona (the region in which the coronal magnetic field transitions from closed to open), and to provide improved detection and tracking of solar eruptive events for space weather research.

## Mission Goals and Objectives

1. Understand the physical processes that alter the magnetic connectivity of the corona from closed to open and open to closed.

A. Observe steady coronal structures and their source region from the solar disk to the upper corona.

B. Observe the temporal changes of the magnetic connectivity due to solar activity.

C. Understand the hot coronal plasma associated with the magnetic structures both on and off disk.

2. Understand the global thermal structure of the corona.

A. Observe the evolution of active regions and associated changes in the slow solar wind.

B. Characterize the temperature profile of the hot plasma associated with the slow solar wind.

C. Measure the temperature and density changes associated with EUV waves, streamers and coronal cavities.

3. Trace the early evolution of coronal mass ejections and prominences as they propagate into the interplanetary medium and create space weather.

A. Observe the locations, velocities and acceleration profiles of coronal mass ejections from their on-disk source regions to  $>2.5R_{\odot}$ .

B. Characterize the background plasma environment before the CME eruption.

C. Identify the CME shock structure and identify regions of possible particle acceleration into interplanetary space.

## Technical Overview

**Design:** SAO has produced a low-risk design for an EUV instrument with an MSFC pointing platform design

♦ **Non-occulting Coronagraph + Full-disk Slitless Spectrometer**

♦ Wavelength: 185-205 Å

♦ Field of view: Full disk out to  $3+ R_{\odot}$

♦ Cadence: 10 s to 1 minute

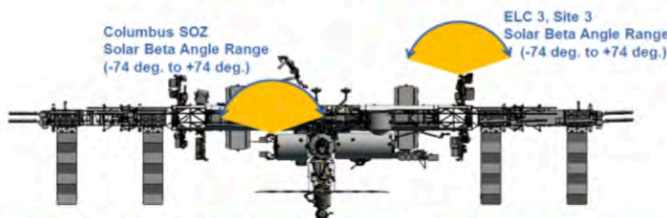
♦ Plate Scale:  $\sim 3$  arcsec/pixel

♦ Pointing Stability: Pointing platform plus tip/tilt primary keeps image stable within the resolution element over the integration period

♦ Integration:  $\sim 4$  s

♦ Sensitivity: 1000x current capability

## Mission Implementation



Solar viewing analysis for two representative ISS external site locations

Solar Viewing Capabilities at ISS Mounting Locations	Solar Viewing Opportunities (Days/Year)	Mount Case Solar Viewing Time per Day	Mount Case Solar Viewing Time per Day	Total Solar Viewing Time per Year
Columbus SO2 or ELC 3-3	365 days	28 min	7.2 hrs	2,640 hrs

Novel graded filter, prime focus imaging, high throughput, give the coronagraph unprecedented sensitivity: 1,000X current capability.

**Additional scientific capability and value with overlap-o-gram channel.**

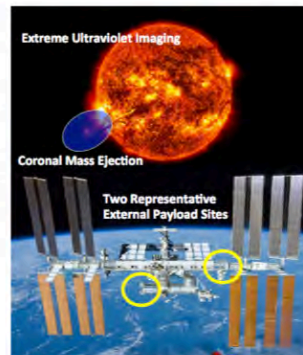
▪ Slitless spectrometer disperses full solar image in spectral direction.

- Compressed in  $\lambda$  direction for image separation.

- Heritage components.

- Less restrictions required for EUV versus white light coronagraph.

- No need for an occulter; not sensitive to dust or scattering, direct response to (CMEs).



Smithsonian Instrument

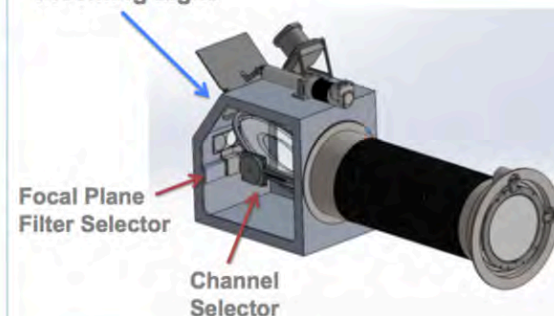
MSFC Integration Deployment

Pointing Avionics

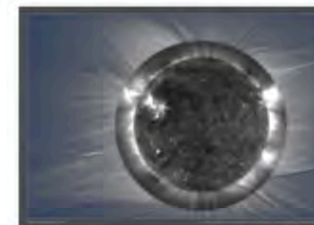
Flight Releasable Attach Mechanism (existing)

## EUVC Instrument Design

Incoming Light



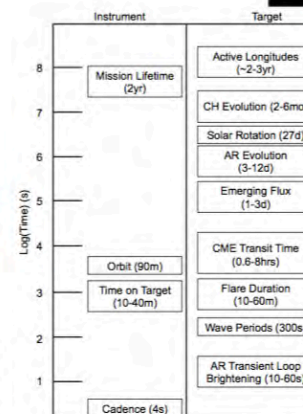
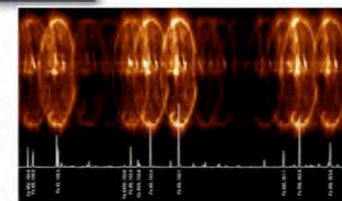
## Mission Products



Spaceweather events and coronal magnetic connectivity are tracked through the corona:

EUV coronagraphs allow for visibility of both the source region and the propagating disturbance.

Spectral images provide plasma diagnostics (temperature, density and LOS velocity for fast flows  $\sim 100$ km/s).



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# Hi-C 2 Status

- Beautiful flight, even after a week of delay
- Science images not captured due to the camera shutter not opening
- Loads of calibration images from the new MSFC camera design
- Achieved low noise requirements
- Anxious to reflly

